EFFECT OF CONCENTRATE SOURCES AND LEVELS ON THE PERFORMANCE AND RUMEN VARIABLES OF GROWING STEERS CONSUMING BERMUDAGRASS HAY

By

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To my mother whose love, support, honesty, convictions and encouragement put me in the path of excellence for doing things. Unfortunately she is reading this work in heaven.

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TABLE OF CONTENTS

ACKNOWLEDGMENTS iii

LIST OF TABLES vi

LIST OF FIGURES xi

ABSTRACT xii

CHAPTERS

I INTRODUCTION 1

II LITERATURE REVIEW 3

Introduction 3
Supplementation of Forage Based Diets 5
Effects of Energy Supplementation on Animal Performance 7
Effects of Supplementation on Forage Intake and Digestibility 16
Effects of Supplementation on Rumen Metabolism 28
Summary 42

III EFFECT OF CONCENTRATE SOURCE AND CONCENTRATE LEVEL ON FORAGE INTAKE AND PERFORMANCE OF STEERS AND INTAKE AND TOTAL DIET DIGESTIBILITY OF SHEEP. 45
Introduction 45
Materials and Methods 46
Results and Discussion 58
Summary and Conclusions 89

IV EFFECT OF CONCENTRATE SOURCE ON DIGESTION AND RUMEN VARIABLES OF STEERS 90

Introduction 90
Materials and Methods 91
Results and Discussion 104
Summary and Conclusions 142

V SUMMARY AND CONCLUSIONS. 144

APPENDIX 149

LITERATURE CITED 200

BIOGRAPHICAL SKETCH 212

LIST OF TABLES

Table Page

2-1 Effect of supplementation on ADG of cattle fed different forages 9

2-2 Effect of grain supplementation on ADG of cattle fed bermudagrass based diets 11

2-3 Effect of corn and byproduct supplementation on ADG of cattle fed bermudagrass based diets 13

2-4 Effect of corn supplementation on forage intake and digestibility 19

2-5 Effect of byproduct supplementation on forage intake and digestibility 23

2-6 Effect of corn supplementation on rumen pH and ammonia-N 31

2-7 Effect of byproduct supplementation on pH and ammonia-N 32

2-8 Effect of corn supplementation on liquid and particulate rates of passage 36

2-9 Effect of byproduct supplementation on liquid and particulate rates of passage 37

2-10 Effect of corn supplementation on VFA 39

2-11 Effect of by-product supplementation on VFA 41

2-12 Effect of supplementation on forage OM and NDF disappearance 43

3-1 Planned orthogonal contrasts used in the analysis of intake and performance trial with cattle and total diet digestibility with sheep 54

3-2 Coefficient of variation (%) for full and shrunk weights of cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) (1992-1993) 60

3-3 Chemical composition of bermudagrass hay and concentrates fed to steers and heifers (Year 1) . . 61

Table Page

3-4 Chemical composition of bermudagrass hay and concentrates fed to steers (Year 2) 62

3-5 Calculated TDN intake from concentrates, as percent of total TDN intake, by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) 63

3-6 Performance by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in 1992 and 1993 64

3-7 Plasma urea nitrogen (PUN) in growing cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) 69

3-8 Intake (% BW) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in 1992 and 1993 71

3-9 Intake (% BW) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 1 . . 72

3-10 Intake (% BW) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 2 . . 73

3-11 Chemical composition of bermudagrass hay and concentrates fed to sheep (Year 1) 79

3-12 Chemical composition of bermudagrass hay and concentrates fed to sheep (Year 2) 80

3-13 Total tract organic matter digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) (1992-1993) 81

3-14 Total tract neutral detergent fiber digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM) or soybean hulls (SBH) (1992-1993) 84

4-1 Assignment of treatments in Latin Square design . . 92

Table Page

4-2 Chemical composition of bermudagrass hay and concentrates fed to steers 105

4-3 Least square means for dry matter intake (% BW) by steers fed different concentrate sources 107

4-4 Rumen and total tract dry matter digestibility using chromium oxide (Cr_2O_3) 109

4-5 Rumen and total tract organic matter digestibility using chromium oxide (Cr_2O_3) 110

4-6 Rumen and total tract NDF digestibility using chromium oxide (Cr_2O_3) 111

4-7 Least square means for digestion kinetics of DM in concentrates using nylon bags 115

4-8 Least square means for digestion kinetics of NDF in concentrates using nylon bags 117

4-9 Least square means for digestion kinetics of DM in hay using nylon bags 118

4-10 Least square means for digestion kinetics of NDF in hay using nylon bags 119

4-11 Rumen liquid kinetics using Cobalt 120

4-12 Digesta kinetics for small particles using Dysprosium 123

4-13 Digesta kinetics for large particles using Ytterbium 125

4-14 Least square means for ammonia and PUN concentration 127

4-15 Least square means for rumen liquid pH 132

4-16 Least square means for total and molar proportions of VFA 135

A3-1 Percentage of TDN intake from concentrates by animal, treatment and year 155

A3-2 Intake (kg d^{-1}) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) (Year 1) . . 157

Table Page

A3-3 Intake (kg d^{-1}) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) (Year 2) . . 158

A3-4 Hay and concentrate intake (% BW) by growing steers 159

A3-5 Dry matter intake (% BW) by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in 1992 and 1993 160

A3-6 Dry matter intake (% BW) by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 1 . 161

A3-7 Dry matter intake (% BW) by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 2 . 162

A3-8 Total tract organic matter digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 1 163

A3-9 Total tract organic matter digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 2 164

A4-1 Hay and concentrate intakes by steers during sampling phase 165

A4-2 Least square means for diurnal variation of rumen liquid ammonia concentration 166

A4-3 Least square means for diurnal variation of rumen liquid pH 167

A4-4 Least square means for diurnal variation of molar proportions of acetate 168

A4-5 Least square means for diurnal variation of molar proportions of propionate 169

A4-6 Least square means for diurnal variation of acetate to propionate ratio 170

A4-7 Least square means for diurnal variation of molar proportions of butyrate 171

Table Page

A4-8 Codes for variables measured in experiments . . . 172

Raw data from experiments 175

LIST OF FIGURES

Figure Page

3-1 Total digestible organic matter intake (DOMI) and shrunk average daily gain (ADG) for different supplement levels and sources (corn-soybean meal, CSBM; wheat middlings, WN and soybean hulls, SBH) . 77

4-1 Diurnal variation of rumen liquid ammonia concentration (mg dL) for steers fed different concentrate sources 128

4-2 Diurnal variation of rumen liquid pH for steers fed different concentrate sources 133

4-3 Diurnal variation in molar proportions of acetate for steers fed different concentrate sources . . . 137

4-4 Diurnal variation in molar proportions of propionate for steers fed different concentrate sources . . . 138

4-5 Diurnal variation of acetate to propionate ratio for steers fed different concentrate sources 140

4-6 Diurnal variation in molar proportions of butyrate for steers fed different concentrate sources 141

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By

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Growing cattle consuming perennial warm season forages often need supplements to achieve high levels of performance. Highly digestible byproducts such as wheat middlings (WM) and soybean hulls (SBH), have lower levels of starch than corn and may not depress forage intake and utilization as much as corn. Corn-soybean meal (CSBM), WM and SBH were fed at two levels (25 and 50%) of projected total TDN intake to growing steers given ad libitum access to bermudagrass hay.

Hay intake was similar for cattle fed hay alone (1.99% body weight; BW) and with all supplements at the low level (1.93% BW), but at the high level of supplementation hay intake was depressed (P=.0001) similarly (1.63% BW) in steers supplemented with CSBM, WM or SBH. At the low feeding level, shrunk average daily gain (ADG) was similar (.63 kg d^{-1}) for all supplements, but at the high feeding level, steers fed SBH had higher (P=.06) shrunk ADG (.95 kg d^{-1}) than steers fed CSBM (.76 kg d^{-1}).

Digestibilities of organic matter (OMD) and neutral detergent fiber (NDFD) were determined with sheep fed levels of hay and concentrates similar to those used in the performance trial. Total tract OMD was lower (P=.0001) for WM (54.8 and 56.9% for low and high levels) compared to CSBM (57.4 and 62.6%) and SBH (57.2 and 62.5%). Total tract NDFD was higher (P=.0001) for the SBH (58.9 and 63.3% for low and high levels) diets than CSBM (54.6 and 51.0%) or WM (54.6 and 51.8%) diets. Sheep fed CSBM and WM at the high feeding level had reduced NDFD compared to sheep fed hay alone (51.0 and 51.8% vs 55.8%).

Rumen variables were determined in a Latin Square design with four cannulated (rumen and duodenal) steers supplemented with CSBM, WM or SBH at the high feeding level. Steers fed WM had the highest (8.0 mg dL^{-1}) rumen fluid ammonia concentration. Supplements increased (P=.01) concentration of total volatile fatty acids and decreased (P=.01) rumen fluid pH, but values were never below 6.1. The lowest acetate to propionate ratio was for WM (2.65). Rates of passage for small particles were faster (P=.05) for SBH.

CHAPTER I

INTRODUCTION

Population growth and the desirability of meat in the human diet have increased the demand for livestock products. Beef cattle production can be increased by supplementing forage-based diets with concentrate feeds. Many byproduct feeds available after processing grains and other seeds for human and monogastric animal diets have considerable nutrient content and most of these byproducts are not useful in human diets.

Growing cattle fed perennial warm season forages often need supplements to achieve high levels of performance. Corn and molasses based supplements improve cattle performance but reduce forage intake and utilization when fed at high levels. Highly digestible byproducts such as wheat middlings (WM) and soybean hulls (SBH), have lower levels of starch than corn and may not depress forage intake and utilization as much as corn at higher levels of supplementation.

The present work was designed to evaluate the effects of different energy concentrates (corn-soybean meal, WM and SBH) containing different types of carbohydrates on (1) forage intake and performance of growing cattle, (2) forage intake and total diet digestibility of sheep and (3) rumen variables of steers consuming bermudagrass (*Cynodon dactylon* L.) hay as based diets.

CHAPTER II

LITERATURE REVIEW

Introduction

Beef cattle production is based on forages which are usually high in fiber concentration and low in concentrations of digestible energy and protein. Thus, protein and energy supplements are often required to meet the nutrient needs of these animals.

A common supplement used in livestock production is a mixture of corn and soybean meal; however, other attractively priced byproducts are often available. Soybean hulls (SBH) and wheat middlings (WM) are byproducts with highly digestible fiber. They can be used as a source of supplemental energy for beef cattle (Brown and Weigel, 1993; Martin and Hibberd, 1990; Ovenell et al., 1991; Anderson et al., 1988b; Hsu et al., 1987).

The soybean hulls are the seedcoats of the soybean seeds removed from the bean during processing. Once the seed and hull are separated by air, the hulls are toasted and ground (Brown and Weigel, 1993). Soybean hulls have high concentrations of digestible fiber and contain little or no starch (Brown and Weigel, 1993; Martin and Hibberd, 1990). They are low in lignin concentration (1.8 to 2.0% acid detergent lignin; ADL), and cellulose represents the majority of the cell wall. The SBH cell wall digests at approximately 7.0% h^{-1}, and up to 95% of the cell wall is digestible. In vitro organic matter digestion (IVOMD) of SBH averages 78 to 80%, and the crude protein (CP) concentration ranges from 12 to 14%.

Soybean hull supplements usually have less negative associative effects on forage digestion than has been observed with corn or molasses supplements (Martin and Hibberd, 1990; Brown and Weigel, 1993). In grazing studies SBH appeared to be equivalent (as fed basis) to corn in improving gains when fed as a supplement to cattle fed forage-based diets. This is unusual because their total digestible nutrient (TDN) concentration was markedly lower (90% for corn vs 64% for SBH; NRC, 1984) (Martin and Hibberd, 1990).

Wheat middlings comprise the layer of the wheat kernel just inside the outer bran covering. They contain granular particles with different proportions of endosperm bran, ground weed seed and other non-wheat materials. Wheat middlings contain approximately 17 to 21% CP, moderate amounts (40%) of rapidly degradable fiber (14.4% h^{-1}) (Sunvold et al., 1991), and have been demonstrated to be an excellent source of supplemental energy for beef cattle (Ovenell et al., 1991). In some situations they have been used as a protein supplement (Sunvold et al., 1991; Cox et al., 1989; Lusby and Wetteman, 1988a).

Supplementation of Forage Based Diets

Supplementation may be defined as any addition to the diet which provides deficient nutrients. These nutrients enable animals to survive, to reproduce, or to increase the efficiency of feed utilization (Siebert and Hunter, 1981; Cronjé, 1990).

The effects of supplements upon animal performance when forage-based diets are fed depend on associative nutritive effects. These have been defined by Ellis (1990) as the greater or smaller nutritive potential of two feeds than the sum of the two feeds fed alone. The associative nutritive effects influence intake and utilization of forages.

Factors related to voluntary intake of forages, when they are fed alone, include their chemical composition, physical characteristics, rate and extent of digestion, and rate of passage through the digestive tract (Zorrilla-Ríos, et al., 1985). When supplements are fed with forage-based diets, factors which affect the direction and extent of change in forage intake and utilization include (in addition to forage properties) the composition of the concentrate (Horn et al., 1991), the amount, frequency, and time of day when concentrates are fed, and the physiological status of the animal (Lusby and Wagner, 1986; Moore, 1992).

Furthermore, nutrient imbalances or deficiencies may depress feed intake, and antiquality factors (e.g., phenolics) might inhibit protein digestibility, and may or may not inhibit dry matter intake (Holderbaum, 1989).

The TDN:CP ratio of the forage may be used to indicate when the supplementation of protein can be beneficial (Moore, 1992). When the TDN:CP ratio is less than seven, it is considered that there is adequate protein to match the energy in the forage and protein supplementation usually does not increase intake for that forage, assuming there are no other limiting factors for voluntary intake (NRC, 1984; Moore, 1992). However, when the TDN:CP ratio is higher than seven there is a deficiency of protein relative to the energy available in the forage (Brant, 1993). In this case suboptimal rumen fermentation can result, and reduced forage intake is likely. Low TDN:CP ratios are common for bermudagrass (75% of samples tested; Moore, 1992) produced in Florida.

The nitrogen (N) concentration in bermudagrass is considered adequate to support the microbial growth set by the energy available from its fermentation alone, or with added corn (Goetsch et al., 1991). In addition, Moore (1992) also suggested that for levels of performance above maintenance, bermudagrass would not require protein supplementation in order to meet requirements.

Feeding high protein supplements (30% CP or greater) to cattle fed low to medium quality forages, usually increases forage intake (Lusby and Wagner, 1986). For example, Guthrie et al. (1984) reported that increasing levels, from 0 to 680 g d^{-1}, of soybean meal (SBM) supplemented to heifers (218 kg) consuming prairie hay with 5.2% CP increased hay intake. Similarly, McCollum and Galyean (1985) reported a 27% increase in prairie hay intake (6.1% CP) when 0.79 kg of cottonseed meal were supplemented to heifers (213 kg).

Effects of Energy Supplementation on Animal Performance

Additional energy provided to growing cattle fed forage-based diets usually increases performance. Levels of performance are related to animal factors (age, sex, weight, physiological status), forage characteristics (species, maturity, management), supplement provided (type, amount, feeding regime), and associative effects between forage and concentrates.

Considerable research has been conducted on supplementation of forage-based diets fed to beef cattle. Research reviewed was limited to studies comparing supplements of corn-soybean meal (CSBM), soybean hulls and(or) wheat middlings fed to growing cattle when performance, intake and digestibility were measured, or when those supplements were fed to growing cattle or mature animals when rumen metabolism was studied. Only a few cow trials have been conducted using SBH and WM, where performance and body condition score (BCS) were reported.

This review does not consider experiments that did not include an unsupplemented treatment, experiments that included CSBM, SBH and(or) WM as ingredients of a total mixed ration and experiments that restricted forage intake. Several of the reviewed trials required data adjustments. Forage and supplement intakes were converted to percentage of body weight to facilitate comparisons. Although effects of supplementation on forage intake, total diet digestibility and rumen variables will be discussed separately, they are interrelated.

Forage quality is one factor that influences animal performance. In a two-year trial, Higgins et al. (1991) fed corn-soybean meal (95% corn and 5% soybean meal) at .75% body weight (BW) to yearling steers consuming four different bermudagrass hays. They reported average daily weight gains (ADG) ranging from .66 to 1.16 kg d^{-1} for supplemented animals, with highest performance for hays with higher organic matter intake (Table 2-1). Similarly, supplementation of cattle grazing tall fescue with corn or bermudagrass hay (Stokes et al., 1988) resulted in higher ADG for the corn treatment in both endophyte-infected and noninfected pastures (Table 2-1).

Table 2-1. Effect of supplementation on ADG of cattle fed different forages.

Reference, forage, type of animal and duration of trial	Supplement	Amount of supplement (% BW)	ADG, kg d^{-1}
Stokes et al. (1988) (Steers and heifers 184 kg; 77 d)	None-INF	0	.21
	None-NOI	0	.29
	Bermudagrass-INF[a]	Ad libitum	.19
	Bermudagrass-NOI[b]	Ad libitum	.29
	Corn-INF	.88	.44
	Corn-NOI	.88	.43
Higgins et al. (1991) (Bermudagrass; steers, 261, 341 kg)	None	0	.34
	Corn-SBM	.75	.91

[a] INF is infected fescue.
[b] NOI is noninfected fescue.

Supplements fed to cattle consuming forage-based diets resulted in higher ADG than for nonsupplemented cattle (Brown and Weigel, 1993; Galloway et al., 1993a; Goetsch et al., 1991; Horn et al., 1991; Anderson et al., 1988a; Anderson et al., 1988b), and weight gains were positively correlated to the amount of supplement provided (Brown and Weigel, 1993; Ovenell et al., 1991; Anderson et al., 1988b).

Responses in ADG are also influenced by type of grain supplement. In a study of growing animals fed different grains at 1% BW, Galloway et al. (1993a) reported 42% higher ADG for ground corn, sorghum grain and whole corn than unsupplemented animals. Animals fed barley and wheat had 31 and 8% greater ADG than the control animals, respectively (Table 2-2). They suggested that differences among grains in ADG most likely involved degrees of modification of rumen conditions (e.g., pH and starch availability) that influence forage intake or digestion.

Increased ADG has been observed with different ingredients or additives in the base supplement. Hardin et al. (1989) supplemented growing animals grazing bermudagrass with corn, corn plus fat, corn plus fat plus urea or corn plus fat plus urea plus blood meal. They reported higher ADG as more ingredients were added to the base corn supplement. A corn supplement with added fat, urea and blood meal produced 36% higher ADG than unsupplemented animals, and was 25% and 14% better than corn alone and corn plus fat plus urea, respectively. Increases in performance with additional ingredients in supplement were attributed to increased fiber digestion, and protein protection for passage to the small intestine in the case of diets containing fat (Table 2-2).

Goetsch et al. (1991) supplemented heifers and steers with .5% BW of ground corn alone or ground corn plus a mix of protein meals (50% feather meal, 25% corn gluten meal, 15% blood meal, and 10% SBM). They reported 46% higher ADG in supplemented than unsupplemented animals, but similar ADG among supplements. When the same authors supplemented beef steers grazing bermudagrass with different combinations of corn and the same protein meal mix, they found that ADG was affected by supplement, age, implant, and supplement by

Table 2-2. Effect of grain supplementation on ADG of cattle fed bermudagrass-based diets.

Reference, forage, type of animal and duration of trial	Supplement	Amount of supplement (% BW)	ADG, kg d^{-1}
Galloway et al. (1993) (Bermudagrass; steers, 250 kg; 84 d)	None	0	.47
	Ground corn	1	.84
	Whole corn	1	.80
	Sorghum grain	1	.81
	Barley	1	.68
	Wheat	1	.51
Hardin et al. (1989) (Bermudagrass; steers, 263, heifers 259 kg; 84 d)	None	0	.63
	Corn	.25	.70
	Corn	.75	.78
	Corn-fat	.75	.84
	Corn-fat-urea	.75	.87
	Corn-fat-urea-blood meal	.75	.99
Goetsch et al. (1991) (Bermudagrass, ryegrass; heifers, 240 kg; steers, 272 kg; 84 d)	None	0	.39
	Corn	.5	.69
	Corn-protein	.5	.75
	Corn-salt	.5	.76
Goetsch et al. (1991) (Bermudagrass, ryegrass; steers, 230 kg; 84 d)	None-no implant	0	.37
	None-implant	0	.37
	Corn-no implant	.5	.56
	Corn-implant	.5	.62
	Corn-protein-no implant	.5	.68
	Corn-protein-implant	.5	.54

implant interaction. Non-implanted steers receiving corn and the protein meal mix had the highest ADG (46% more weight gain than unsupplemented cattle) (Table 2-2).

Identification of attractively priced byproducts is an important task in developing a profitable beef cattle operation. Soybean hulls and wheat middlings have demonstrated economic and production advantages when compared to corn. In a series of grazing trials with growing beef calves maintained on either smooth bromegrass or corn residue pastures, Anderson et al. (1988a) compared SBH and corn as energy supplements. They reported better performance of supplemented than unsupplemented cattle, and similar ADG for SBH and corn. Similar gains among concentrates were found when corn or SBH were supplemented and fed either pelleted, ground or rolled. The same response in ADG was found in cattle grazing on smooth bromegrass or corn stalks, and fed three different regimens of SBH (same amount all season long, higher amounts given in only the second half of the season or weekly incremental increases of SBH) (Table 2-3).

Anderson et al. (1988b) also mentioned SBH as a viable alternative to grains as energy supplements in high forage diets. When SBH (whole or ground) and corn were fed at two levels (.63 and 1.25% BW), they found that higher levels of supplement increased daily gains, but sources were not different. They suggested that SBH have fewer negative

Table 2-3. Effect of corn and byproduct supplementation on ADG of cattle fed forage-based diets.

Reference, forage, type of animal and duration of trial	Supplement	Amount of supplement (% BW)	ADG, kg d^{-1}
Anderson et al. (1988a)	None	0	1.04
(Smooth brome; steers,	Whole SBH	.53	1.13
256 kg; 86 d)	Rolled corn	.53	1.14
Anderson et al. (1988a)	None	0	.60
(Smooth brome; heifers	Rolled corn	.56	.75
243 kg, steers, 236 kg;	Ground SBH	.56	.77
138 d)	Whole SBH	.56	.78
(Cornstalk plus protein	None	0	.73
supplement; heifers, 189	Rolled corn	.72	.85
kg; 51 d)	Whole SBH	.72	.90
Anderson et al. (1988b)	None	0	.52
(Indiangrass hay,	Corn	.97	.73
alfalfa hay, ammoniated	Ground SBH	.97	.76
oat straw; steers, 235	Whole SBH	.97	.69
kg; 112 d)	Corn	1.96	.92
	Ground SBH	1.96	.85
	Whole SBH	1.96	.84
Brown and Weigel (1993)	None	0	.45
(Bahiagrass, stargrass	Molasses	.57	.61
hay; steers, 240 kg)	Corn	.57	.77
	SBH	.57	.73
	Molasses	1.13	.77
	Corn	1.13	.91
	SBH	1.13	.95
Heird et al. (1994)	None	0	.56
(Bermudagrass, fescue;	Corn-protein	.81	1.09
steers, 236 kg; 84 d)	SBH-protein	1.11	1.20
Horn et al. (1991)	None	0	.97
(Wheat pasture; steers,	Corn	.71	.99
210 kg; 115 d)	SBH-WM	.72	1.07
	SBH-WM	.84	1.02

associative effects on fiber digestion than corn when used as an energy supplement, and appear to be essentially equal in supporting growth of calves fed forage-based diets (Table 2-3).

Brown and Weigel (1993) reported higher ADG in supplemented than unsupplemented yearling cattle grazing bahiagrass, and fed ammoniated stargrass hay plus cottonseed meal. Supplements included molasses, cracked corn or SBH. All three energy supplements at both levels improved daily gain and feed efficiency compared to the control. Higher levels of SBH and corn produced 50% higher weight gains than the control, while the higher level of molasses supplementation produced ADG similar to the lower level of SBH and corn. They suggested that SBH have a digestible energy value equal to corn and can be fed at high levels without health problems, such as acidosis (Table 2-3).

Heird et al. (1994) evaluated corn and SBH supplements in steers grazing mixed pastures of fescue and bermudagrass. Steers supplemented with SBH had 53% greater ADG than unsupplemented steers and 10% higher ADG than steers supplemented with corn (Table 2-3).

Horn et al. (1991) fed a corn supplement, or a high fiber energy supplement (47% SBH plus 46% WM) daily or six days of the week to steer calves grazing wheat pasture. They reported 5% higher weight gains in supplemented than unsupplemented animals, and also higher ADG (8%) in the high fiber supplement than the corn diet (Table 2-3).

Wheat middlings have been used as an energy source, but their crude protein concentration represents an additional advantage for their utilization in cattle. Feeding similar amounts (1.4% BW) of different supplements (corn plus SBM, corn plus cottonseed, SBH or WM) to growing steers consuming ground hay ad libitum, Allison and Poore (1992) reported higher ADG for animals receiving the SBH diet, which was also the most cost effective. Daily gains of other supplements were similar, but WM and corn plus whole cottonseed were an economical alternative to corn plus SBM which was the most expensive of all supplements.

In a year-long supplementation trial, Ovenell et al. (1991) fed WM at .3, .63, and .75% BW or soybean meal at .3% BW to beef cows grazing dormant native tallgrass range. They found similar weight and body condition changes among supplements. Feeding higher amounts of WM significantly increased cow weight before calving and calf birth weights. They also reported increased weaning weights in WM supplemented cattle which suggested greater milk production. Body condition scores in all cases reflected changes in body weight. They concluded that it is not necessary to feed WM at isonitrogenous levels of SBM to achieve equal cow weight changes and calf weaning weights. They suggested that .63% BW of a WM supplement resulted in adequate performance in cows grazing on dormant native tallgrass. In several experiments with brood cows grazing on dormant native tall grass during fall and spring, similar responses in body weight changes and BCS were found when WM alone or combined with SBM were the supplements (Cox et al., 1989; Ovenell et al., 1989; Lusby and Wetteman, 1988a; Lusby and Wetteman, 1988b).

Supplementation to beef cows with increasing amounts of WM produced lower weight losses during winter (Cox et al., 1989). Feeding WM also reduced weight losses compared to feeding isonitrogenous levels of SBM (28 kg versus 50 kg for WM and SBM, respectively). In all cases BCS reflected the weight changes observed.

Effects of Supplementation on Forage Intake and Digestibility

Variation in production potential between forages has been attributed mainly to differences in voluntary intake (70%), as compared to differences in digestibility (30%) (Raymond, 1969). However, when supplements are provided to forage-based diets, the intake of the forage may or may not change, and the total diet may or may not increase in digestibility, as compared to the forage alone (Moore et al., 1995).

Supplementation may decrease forage intake when forage TDN:CP ratio is 7 or less. This response is called substitution of supplement for forage. Substitution rate is defined as the decrease in forage DMI per unit of supplement DM fed (Brant, 1993).

Supplementation of corn to cattle consuming forage-based diets reduces forage intake most of the time. However, this response is related to the level of corn provided. Small amounts of corn supplementation (.3% BW approximately) have been shown to increase forage intake (Frederickson et al., 1993; Pordomingo et al., 1991; Chan et al., 1991), but higher levels invariably decrease forage intake.

In addition, corn supplementation of forage-based diets is generally accompanied by increases in dry matter (DM) and organic matter (OM) digestibility and decreases in digestibility of the neutral detergent fiber (NDF). This response occurs because supplements are highly digestible and thus, total diet DM and OM digestibility increases as the amount of supplemental corn increases (Chase and Hibberd, 1987).

Goetsch et al. (1991) summarized 18 experiments conducted to determine feed intake and digestion changes by Holstein steers consuming bermudagrass hay ad libitum. Steers were supplemented with ground corn at 0, .25, .50, .75 or 1.0% BW. They reported that each kilogram (DM basis) of corn consumed increased total DM intake by 0.54 kg and decreased bermudagrass DM intake by 0.46 kg. A consistent change in forage intake was noted with corn levels up to

0.75% of body weight. One kilogram of supplemental corn OM increased total diet OM digestibility by 1.8 percentage units, but decreased bermudagrass OM digestion by 4.2 percentage units. Each kilogram of corn DM decreased bermudagrass NDF digestion by 3.3 percentage units, and each 1% of BW of corn DM decreased NDF digestion by 8.5 percentage units.

A decreased hay intake was reported by Sanson et al. (1990) who studied the effects of increasing amounts of corn added in a protein supplement provided to steers consuming a low quality meadow hay. They compared an isonitrogenous supplement containing 0, .2 or .4% BW of corn starch and reported larger decreases in forage intake as higher amounts of corn were added to the diet (2.0, 1.6% and 1.8% BW of hay intake for 0, .2 or .4% BW of corn starch in diet, respectively). Dry matter and OM digestion increased with increasing amounts of corn consumed when compared with unsupplemented steers. However, NDF digestion decreased as level of corn in the supplement increased, with no difference among levels of corn supplementation (Table 2-4).

A similar decrease in hay intake was described by Chase and Hibberd (1987) when increasing amounts of ground corn (0, .28, .55 and .83 % BW) were supplemented to beef cows consuming chopped native grass. In addition, NDF digestibility decreased from 40 to 26% as the amount of supplemental corn increased in the diet. This response was

Table 2-4. Effect of corn supplementation on forage intake and digestibility.

Reference, forage and type of animal	Forage intake % BW	Forage digestibility (%) OM	NDF
Sanson et al. (1990) (Meadow hay; steers, 550 kg)			
Control	2.1	54.4	49.9
0% BW corn-protein	2.0	60.2	52.7
.2% BW corn-protein	1.6	62.8	51.1
.4% BW corn-protein	1.8	64.3	49.5
Chase and Hibberd (1987) (Native grass hay; beef cows 362 kg)			
Control	2.30	36.5	39.6
.28 % BW ground corn	2.14	35.1	38.5
.55 % BW ground corn	1.66	23.6	29.9
.83 % BW ground corn	1.32	18.9	25.6
Pordomingo et al.(1991) (Native rangeland; steers, 507 kg)			
Control	2.76	NR[a]	NR
.2 % BW whole shelled corn	2.95	NR	NR
.4 % BW whole shelled corn	2.26	NR	NR
.6 % BW whole shelled corn	1.98	NR	NR
Frederickson et al.(1993) (Prairie hay; steers, 194 kg)			
Control	1.43	NR	NR
Dry rolled corn .32% BW plus urea	1.44	NR	NR

[a] NR: not reported

Table 2-4.--- continued.

Reference, forage and type of animal	Forage intake % BW	Forage digestibility (%) OM	NDF
Hall et al. (1990) (Bermudagrass; steers, 248 and 324 kg)			
Control	2.39	54.9	59.0
.5% BW corn-bicarbonate	2.26	60.6	59.0
1% BW corn-bicarbonate	1.94	64.8	60.4
Control	2.85	57.0	61.9
.24% BW corn-methionine	2.75	61.1	63.7
.74% BW corn-methionine	2.60	64.7	63.0
Galloway et al. (1993a) (Bermudagrass; steers, 210 kg)			
Control	2.97	50.9	52.9
1% BW ground corn	2.51	54.1	47.2
1% BW whole corn	2.50	54.9	48.5

attributed to increased starch consumption. However, the slight depression in NDF digestion found at the low corn level (.28% BW) suggests that small quantities of grain (.3% BW) may not decrease hay utilization to the same extent that larger quantities do (.6 or .9% BW) (Table 2-4).

Pordomingo et al. (1991) also found differences in forage intake when shelled corn was supplemented to steers consuming native rangeland. Compared to unsupplemented animals, forage intake was increased 7% with .2% BW of corn and decreased 18% and 28% when .4 and .6% BW of corn was supplemented (Table 2-4).

No effect on hay intake in cattle receiving corn supplementation was reported by Frederickson et al. (1993) when growing steers were fed with prairie hay or prairie hay plus corn-urea at .32% BW. In this trial, the increase in digestible energy intake that resulted from corn supplementation did not affect forage intake (Table 2-4).

Research by Sanson and Clanton (1989) reported no effect on NDF digestibility when increasing amounts of corn were provided to cattle, although decreased hay intake and increased OM digestibility were recorded. Contrary to these results, Galloway et al. (1993a) found a 10% decrease in NDF digestibility when steers were fed 1% BW of ground or whole corn (Table 2-4).

Different additives have been used successfully to reduce the negative associative effects on forage digestibility when corn supplement is fed to cattle. Hall et al. (1990) added sodium bicarbonate (B) or DL-methionine (M) to different amounts of supplemental ground corn fed to Holstein steers consuming bermudagrass hay ad libitum. They found a decrease in hay DMI as level of corn increased in the diet using both buffers. As expected, OM digestion increased as supplement level increased. In this experiment there was no difference in total tract NDF digestion between supplemented and unsupplemented animals (Table 2-4).

Beneficial associative effects of highly digestible fiber supplements are related to the lower decreases in forage intake and NDF digestibility. Galloway et al. (1993b) reported similar total OM intake when corn or SBH were supplemented at .5% or .7% BW to steers consuming bermudagrass hay ad libitum. Digestibility of NDF was higher by 5 percentage units for SBH than corn which had even lower NDF digestibility than unsupplemented steers (Table 2-5).

Positive responses in hay intake have been reported when feeding SBH at low levels of supplementation. Brown and Weigel (1993), placed growing calves on bahiagrass pasture and fed ammoniated stargrass hay plus .45 kg of cottonseed meal per head per day. Animals were supplemented with .57% or 1.13% BW of either molasses, cracked corn or SBH per head per day, fed three times per week. At the lower level of supplementation, hay intake was not reduced

Table 2-5. Effect of byproduct supplementation on forage intake and digestibility.

Reference, forage and type of animal	Forage intake % BW	Forage digestibility (%) OM	NDF
Galloway et al. (1993b) (Bermudagrass; steers, 210 kg)			
Control	2.4	52.7	56.4
.5% BW Corn	2.3	56.3	53.9
.7% BW SBH	2.1	56.2	58.1
Brown and Weigel (1993) (Bahiagrass, stargrass hay, cottonseed meal; steers, 240 kg)			
None	2.87	NR[a]	NR
.57 % BW Molasses	2.45	NR	NR
.57 % BW Corn	2.83	NR	NR
.57 % BW SBH	2.98	NR	NR
1.13 % BW Molasses	2.57	NR	NR
1.13 % BW Corn	2.28	NR	NR
1.13 % BW SBH	2.49	NR	NR
Scott and Hibberd (1990) (Native grass hay; beef cows 538 kg)			
Control	.70	46.6	NR
.35 % BW SBH	.98	54.9	NR
Martin and Hibberd (1990) (Native grass hay; beef cows, 453 kg)			
Control	2.14	45.8	47.7
.22 % BW SBH	2.24	46.2	46.8
.44 % BW SBH	2.17	46.6	46.7
.66 % BW SBH	2.00	48.6	48.1

[a] NR: not reported.

Table 2-5. ---continued.

Reference, forage and type of animal	Forage intake % BW	Forage digestibility (%)	
		OM	NDF
Trautman et al. (1987) (Native grass hay; beef cows, 537 kg)			
Control	1.11	52.1	NR[a]
.34 % BW SBH	1.46	50.6	NR
.59 % BW SBH	1.55	52.2	NR
Chan et al.(1991) (Native grass hay; beef cows, 542 kg)			
Control	1.01	46.7	59.6
.28 % BW corn	1.23	58.1	60.4
.55 % BW corn	1.19	61.2	59.8
.28 % BW SBH	1.40	58.8	66.3
.55 % BW SBH	1.20	58.8	66.2
Heird et al. (1994) (Native grass hay; steers, 161 kg)			
Control	2.74	47.1	47.5
.75 % BW corn-monensin	2.10	58.9	52.8
1.05 % BW SBH	2.09	62.4	58.7
Arelovich et al. (1983) (Prairie hay; steers, 428 kg)			
Control	.83	45.9	NR
.28 % BW cottonseed meal	1.07	54.2	NR
.36 % BW WM	1.05	56.7	NR
.29 % BW ground wheat	1.07	56.1	NR
Sunvold et al. (1991) (Bluestem range; steers, 374 kg)			
Control	.87	43.9	54.3
.32 % BW Sorghum-SBM	1.07	49.4	51.2
.39 % BW WM	.99	50.6	54.1
.77 % BW WM	1.15	50.4	49.8

[a] NR: not reported.

Table 2-5 ---continued.

Reference, forage and type of animal	Forage intake % BW	Forage digestibility (%) OM	NDF
Ovenell et al. (1991) (Prairie hay; beef cows, 470 kg)			
Control	1.95	52.2	NR[a]
.30 % BW SBM	2.16	60.7	NR
.75 % BW WM	1.94	55.2	NR
.75 % BW Corn-SBM	1.89	52.7	NR
Galloway et al.(1991) (Bermudagrass hay; steers, 193 kg)			
Control	2.70	57.4	64.5
.50 % BW corn	2.36	61.5	64.8
.63 % BW WM	2.26	59.3	60.7
.25 % BW corn-.31 % BW WM	2.29	59.0	61.1

[a] NR: not reported.

for cattle fed corn or SBH compared to control, but steers supplemented with molasses had reduced hay intake compared to control. At the high level of supplementation (1.13% BW), all three energy sources reduced hay intake by 15% compared to control (Table 2-5).

A similar response in hay intake was reported by Martin and Hibberd (1990) who supplemented increasing amounts of SBH (0, .22, .44 and .66% BW) to cows consuming low quality native grass hay. Hay OM intake peaked with .22% BW of SBH, but declined with higher amounts of SBH in the diet. Compared to control, hay OM intake decreased only 6.6% when .66% BW SBH were fed, indicating that ruminal distension from SBH was not the major factor limiting hay intake (Table 2-5). They mentioned that the same type of hay, supplemented with similar levels of corn had a hay intake that was 3.7 kg lower than for SBH fed cattle, showing that SBH have a lower substitution rate of supplement for hay.

Increases in hay intake due to SBH supplementation were also reported by Trautman et al. (1987) feeding SBH at 0, .34 and .59% BW to beef cows consuming low quality native grass hay. They reported 14% and 18% increases in hay intake with increasing levels of SBH. Although digestible OM intake increased with increasing levels of SBH, there was no effect on OM digestion due to SBH supplementation (Table 2-5).

Contrary to these results, Heird et al. (1994) reported a depression in hay DM intake when comparing corn-monensin (.75% BW) and SBH (1.05% BW) supplements fed to growing calves consuming low quality hay and a protein supplement (Table 2-5). In addition, digestion of OM and NDF were higher in supplemented steers than in unsupplemented steers.

Positive effects in both hay intake and NDF digestion were reported by Chan et al. (1991) when SBH or corn supplements were fed. They supplemented beef cows consuming low quality native grass hay with energy and protein supplements containing either corn or SBH at .28 and .55% BW. Hay OM intake increased for supplemented cattle but was not affected by level or source. Rumen and total tract OM digestibility were not affected by source or level of supplement. Compared to corn, SBH increased rumen and total tract NDF digestibility (Table 2-5). They suggested that the increased NDF digestion of SBH may be attributed to increased digestible NDF intake because SBH contain a high concentration of nonlignified NDF.

Cattle supplemented with WM had increased hay intake compared to unsupplemented animals (Arelovich et al., 1983; Sunvold et al., 1991). Supplementation with .28% BW cottonseed meal, .36% BW of WM, or .29% BW of ground wheat to steers consuming low quality prairie hay produced increased hay intake and DM digestibility compared to control (Table 2-5) (Arelovich et al., 1983).

Sunvold et al. (1991) reported increased forage DM intake when sorghum-SBM (.32% BW) and high levels of WM (.77% BW) were fed to steers consuming dormant bluestem range forage. Compared to unsupplemented cattle, total DM intake and DM digestibility increased with supplementation, but no differences were found between supplements. Digestibility of NDF was lower by 5 percentage units for the high level of WM supplementation, as compared to unsupplemented cattle (Table 2-5).

Contrary to these results, hay intake and DM digestibility were better for SBM than WM when fed as supplements to cows consuming prairie hay (Ovenell et al. 1991). Compared to WM and unsupplemented steers, SBM supplementation increased hay DM intake by 10% and hay DM digestibility by 8% (Table 2-5).

A decreased NDF digestibility for WM was reported by Galloway et al. (1991) when feeding .62% BW of WM, or a combination of corn (.25% BW) plus WM (.31% BW) to growing steers consuming bermudagrass hay. Hay DM intake was 15% lower for supplemented animals compared to control, but similar among concentrates. Inclusion of WM in supplements decreased NDF digestion by 4 percent units compared to the control (Table 2-5).

Effects of Supplementation on Rumen Metabolism

The ability of ruminants to utilize cellulose, hemicellulose and pectin as feed depends on the capacity of rumen microorganisms to utilize them and the ability of the host animal to utilize these microorganisms and their products (Van Soest, 1982). Carbohydrate fermentation in the rumen varies according to the kind and number of the microorganisms present, which in turn are under the influence of the food characteristics.

Ammonia concentrations and pH in rumen are major factors that affect type and number of cellulolytic microorganisms. Satter and Slyter (1974) suggested 2 to 5 mg dL^{-1} of ammonia in rumen fluid as the minimum amount that allows adequate growth of rumen microorganisms. In addition, decreased rumen fiber digestion has been observed when ruminal pH declines below 6.2 (Mould and Orskov, 1983).

Effects of supplementation on rumen ammonia concentration are related to the CP concentrations in the base forage and the supplement. When supplements are supplied once a day, concentrations of ammonia in rumen peak 2 to 8 hours postfeeding, then decrease and remain low or high as determined by the TDN:CP ratio of the forage.

Compared with no supplementation, corn may increase (Sanson et al., 1990; Chan et al., 1991), decrease (Brake et al., 1989; Chase and Hibberd, 1987) or not affect (Sanson and Clanton, 1989) rumen ammonia concentration. This depends on the CP concentration of the base forage fed.

Addition of urea to corn increased rumen ammonia concentration up to 8 hours after feeding the grain

(Frederickson et al., 1993) (Table 2-6). Supplementation with increasing amounts of ground corn (0, .28, .55 and .83% BW) to beef cows consuming chopped native grass produced ruminal ammonia concentrations below the recommended minimum level for optimum microbial growth (2 to 5 mg dl^{-1}). These low values (2.20, 1.12, .88 and .61 mg dl^{-1} for 0, .28, .55 and .83% BW of corn) may have limited microbial activity and decreased the rate and extent of fiber digestion (Chase and Hibberd, 1987) (Table 2-6).

Lower than recommended rumen ammonia concentrations were also recorded by Scott and Hibberd (1990) feeding .35% BW of SBH to beef cows consuming a low quality native grass, and by Martin and Hibberd (1990) who supplemented with increasing amounts of SBH (0, .22, .44, and .66% BW). In the latter case, ruminal ammonia concentrations were similar at all supplementation levels and peaked at 2 h postfeeding, then declined at 6 h postfeeding and remained low (< 1 mg dl^{-1}) throughout the day for all SBH levels. They suggested that an increased quantity of OM fermented in the rumen with SBH supplementation may have increased microbial incorporation and decreased ruminal ammonia concentration (Table 2-7).

Other researchers have reported adequate concentrations of rumen ammonia when SBH were supplemented to cattle. Chan et al. (1991) supplemented beef cows consuming low quality native grass hay with concentrates containing either corn or

Table 2-6. Effect of corn supplementation on rumen pH and ammonia N.

Reference, forage and type of animal	Ammonia N (mg dL^{-1})	pH
Frederickson et al. (1993) (Prairie hay; steers, 194 kg)		
Control	.6	6.6
Dry rolled corn .32% BW plus urea	5.2	6.5
Sanson et al. (1990) (Warm season hay; steers, 550 kg)		
Control	1-2	6.3
.3 % BW Corn	3-8	5.8-5.9
.6 % BW Corn	3-7	5.5-5.9
Brake et al. (1989) (Bermudagrass hay; beef cows, 452 kg)		
Control	3.4	6.77
.6 % BW ground corn	2.5	6.67
Chase and Hibberd (1987) (Native grass hay; beef cows 362 kg)		
Control	2.20	6.5
.28 % BW ground corn	1.12	6.6
.55 % BW ground corn	.88	6.4
.83 % BW ground corn	.61	6.3
Sanson and Clanton (1989) (Warm season hay; steers, 418 kg)		
Control	2.0	6.6
.25 % BW whole corn	1.8	6.6
.50 % BW whole corn	1.7	6.4
.75 % BW whole corn	1.9	6.6
Pordomingo et al.(1991) (Native rangeland; steers, 507 kg)		
Control	7-9	NR[a]
.2 % BW whole shelled corn	7-9	NR
.4 % BW whole shelled corn	5-7	NR
.6 % BW whole shelled corn	6-11.5	NR

[a] NR: not reported.

Table 2-7. Effect of byproduct supplementation on rumen pH and ammonia N.

Reference, forage and type of animal	Ammonia N (mg dL^{-1})	pH
Chan et al.(1991) (Native grass hay; beef cows, 542 kg)		
Control	.50	6.7
.28 % BW corn	2.40	6.3
.55 % BW corn	1.47	6.2
.28 % BW SBH	2.86	6.3
.55 % BW SBH	2.21	6.3
Scott and Hibberd (1990) (Native grass hay; beef cows 538 kg)		
Control	<1	NR
.35 % BW SBH	<1	NR
Martin and Hibberd (1990) (Native grass hay; beef cows, 453 kg)		
Control	1.5	6.5
.22 % BW SBH	<1	6.4
.44 % BW SBH	<1	6.3
.66 % BW SBH	<1	6.3
Trautman et al. (1987) (Native grass hay; beef cows, 537 kg)		
Control	5.8	6.42
.34 % BW SBH	7.1	6.34
.59 % BW SBH	2.1	6.36
Arelovich et al. (1983) (Prairie hay; steers, 428 kg)		
Control	.35	NR
.28 % BW cottonseed meal	3.56	NR
.36 % BW WM	2.64	NR
.29 % BW ground wheat	4.44	NR
Sunvold et al. (1991) (Bluestem range; steers, 374 kg)		
Control	1.0	6.9
.32 % BW Sorghum-SBM	1.6	6.7
.39 % BW WM	3.1	6.6
.77 % BW WM	6.1	6.4

SBH at .28 or .55% BW. A 22% increase in rumen ammonia concentration was recorded for high levels of SBH as compared to cattle supplemented with corn (Table 2-7).

Trautman et al. (1987) reported 64% lower ammonia concentrations for the highest level of SBH supplementation (.59% BW) when compared to unsupplemented animals and similar values for the low level of SBH (.34% BW) compared to unsupplemented cows (Table 2-7). The highest level of SBH supplementation resulted in a rumen ammonia concentration below the recommended level.

Arelovich et al. (1983) supplemented .20% BW cottonseed meal, .36% BW of WM, or .29% BW of ground wheat to steers consuming low quality prairie hay. They found no differences among supplements in rumen ammonia concentration although values for WM were the lowest (Table 2-7).

Supplementation of higher levels of WM (Sunvold et al. 1991) produced higher rumen ammonia concentrations for the WM supplemented groups. These researchers fed .32% BW of sorghum-SBM, and .39% or .77% BW of WM to steers consuming dormant bluestem range forage (Table 2-7).

Rumen fluid pH values follow an inverse daily pattern compared to ammonia values. Decreased pH values are usually found from 2 up to 10 hours postfeeding the concentrate, then pH usually increases until the next concentrate feeding. Due to high amounts of readily fermentable carbohydrates (starch), supplementation using corn may reduce rumen fluid pH below 6.2. Sanson et al. (1990) found that corn supplementation decreased rumen fluid pH at 1, 3, 5, and 7 hours postfeeding compared with no supplementation. Rumen fluid pH dropped below 6 when corn was fed at .3% and .6% BW (Table 2-6).

However, although lower rumen fluid pH values generally are recorded for supplemented animals, similar pH values have been reported with increasing levels of corn in the diet (Sanson and Clanton, 1989; Brake et al., 1989; Frederickson et al., 1993; Pordomingo et al., 1993; Chase and Hibberd, 1987) (Table 2-6).

Similar values of rumen pH to those for unsupplemented controls have been observed when SBH or WM were supplemented to cattle (Martin and Hibberd, 1990; Trautman et al., 1987; Arelovich et al., 1983; Sunvold et al., 1991), but pH values did not drop below 6.2 (Table 2-7). Chan et al. (1991) reported higher rumen pH values for unsupplemented than supplemented cattle, and corn supplemented cattle had lower pH values compared to SBH supplemented cattle. In this trial, a decreased ruminal pH and reduced ruminal ammonia concentration were suggested as contributors to the reduced digestibility of NDF in corn supplemented cattle (Table 2-7).

Starch in corn is fermented by rumen bacteria at a more rapid rate than the fiber in SBH or WM. This fermentation results in the production of VFA's which accumulate and reduce ruminal pH. Bacteria which digest forage are sensitive to ruminal pH and when pH drops below 6.2 growth of fiber-digesting bacteria can be inhibited, resulting in reduced forage digestion. Thus, starch alters fiber degradation primarily by increasing digestion lag time (Martin and Hibberd, 1990).

A knowledge of the partition of digestion and passage within the gastrointestinal tract is essential for an understanding of the amounts and proportions of the particular nutrients absorbed (Faichney, 1975). Supplementation of increasing amounts of corn may produce a positive response in particulate passage rate compared to unsupplemented animals (Hall et al., 1990; Brake et al., 1989; Heird et al., 1994). However, corn supplementation may not affect particulate passage rate compared to control animals (Frederickson et al., 1993; Pordomingo et al., 1991), and even may decrease rates of particulate passage compared to unsupplemented animals (Chase and Hibberd, 1987) (Table 2-8). Liquid rate of passage may increase with corn supplementation, relative to control (Brake et al., 1989) (Tables 2-8 and 2-9).

Cattle fed SBH and corn showed higher particulate passage rates than unsupplemented cattle but no difference was detected between concentrates (Heird et al., 1994) (Table 2-9). Martin and Hibberd (1990) reported no difference in rumen liquid rate of passage with increasing

Table 2-8. Effect of corn supplementation on liquid and particulate rates of passage.

Reference, forage and type of animal	Liquid rate of passage, % h^{-1}	Solid rate of passage, % h^{-1}
Hall et al. (1990) (Bermudagrass hay; steers, 248 kg)		
Control	NR[a]	3.48
.5 % BW ground corn	NR	3.74
1 % BW ground corn	NR	3.87
Control	NR	3.62
.24 % BW ground corn	NR	3.99
.74 % BW ground corn	NR	4.35
Brake et al. (1989) (Bermudagrass hay; beef cows, 452 kg)		
Control	6.16	2.77
.6 % BW ground corn	7.79	3.54
Frederickson et al.(1993) (Prairie hay; steers, 194 kg)		
Control	9.0	2.4
Dry rolled corn .32% BW plus urea	9.5	2.7
Chase and Hibberd (1987) (Native grass hay; beef cows 362 kg)		
Control	NR	3.90
.28 % BW ground corn	NR	4.04
.55 % BW ground corn	NR	3.72
.83 % BW ground corn	NR	3.68
Pordomingo et al.(1991) (Native rangeland; steers, 507 kg)		
Control	9.7	3.5
.2 % BW whole shelled corn	11.2	4.1
.4 % BW whole shelled corn	9.4	3.6
.6 % BW whole shelled corn	9.6	3.5

[a] NR: not reported.

Table 2-9. Effect of byproduct supplementation on liquid and particulate rates of passage.

Reference, forage and type of animal	Liquid rate of passage, % h^{-1}	Solid rate of passage, % h^{-1}
Heird et al. (1994) (Native grass hay; steers, 161 kg)		
Control	NR[a]	2.59
.75 % BW corn-monensin	NR	3.02
1.05 % BW SBH	NR	3.10
Martin and Hibberd (1990) (Native grass hay; beef cows, 453 kg)		
Control	8.05	3.28
.22 % BW SBH	9.15	3.81
.44 % BW SBH	8.94	3.71
.66 % BW SBH	9.50	3.59
Scott and Hibberd (1990) (Native grass hay; beef cows 538 kg)		
Control	NR	.80
.35 % BW SBH	NR	1.64
Ovenell et al. (1991) (Prairie hay; beef cows, 470 kg)		
Control	NR	3.2
.30 % BW SBM	NR	3.6
.75 % BW WM	NR	3.7
.75 % BW Corn-SBM	NR	3.7
Sunvold et al. (1991) (Bluestem range; steers, 374 kg)		
Control	5.8	NR
.32 % BW Sorghum-SBM	7.2	NR
.39 % BW WM	7.0	NR
.77 % BW WM	8.2	NR

[a] NR: not reported.

levels of SBH in the diet (Table 2-9). They mentioned that a different response was expected because SBH are a dry, fibrous feed that require more chewing and insalivation. The increased saliva flow could increase ruminal osmotic pressure and water influx, resulting in increased liquid rate of passage. Supplementation with WM or corn increased particulate passage rate as compared to unsupplemented cattle, but no differences between supplements were recorded (Ovenell et al., 1991) (Table 2-9).

Sunvold et al. (1991) reported that supplementation increased rumen DM fill and passage rates. The high level of WM promoted the greatest increase, while sorghum-SBM and the low WM level were intermediate between the control and high WM diets (Table 2-9).

The acids formed by microbial action in the rumen are the end products of various intermediary reactions and represent the energy source for ruminants. The proportion of the acids formed varies with the nature of the ration and the microorganisms present. Increasing amounts of corn in the diet did not alter total volatile fatty acid (VFA) concentration in rumen or the acetate to propionate (A:P) ratio (Sanson and Clanton, 1989; Frederickson et al., 1993; Pordomingo et al., 1991) (Table 2-10).

Chase and Hibberd (1987) also reported similar total VFA concentrations and similar molar proportions of propionate when increasing amounts of corn were fed. In

Table 2-10. Effect of corn supplementation on VFA.

Reference, forage and type of animal	Total VFA mM	Acetate: Propionate
Sanson and Clanton (1989) (Warm season hay; steers, 418 kg)		
Control	NR[a]	4.74
.25 % BW whole corn	NR	4.93
.50 % BW whole corn	NR	4.71
.75 % BW whole corn	NR	4.16
Frederickson et al.(1993) (Prairie hay; steers, 194 kg)		
Control		
.32% BW dry rolled corn	85.6	4.56
plus urea	88.2	4.32
Pordomingo et al.(1991) (Native rangeland; steers, 507 kg)		
Control	108.8	5.05
.2 % BW whole shelled corn	112.4	4.93
.4 % BW whole shelled corn	103.4	4.48
.6 % BW whole shelled corn	112.1	4.38
Chase and Hibberd (1987) (Native grass hay; beef cows 362 kg)		
Control	51.1	3.8
.28 % BW ground corn	51.1	3.6
.55 % BW ground corn	53.5	3.0
.83 % BW ground corn	53.2	3.0

[a] NR: not reported

this trial, molar proportions of acetate decreased and consequently A:P ratio tended to decrease with corn supplementation (Table 2-10).

Addition of monensin to corn diets increased total VFA concentration, which was similar to SBH supplementation (Heird et al. 1994), but different in molar proportions. Acetate was higher for SBH and lower for corn-monensin, conversely, propionate was higher for corn-monensin, and lower for control and SBH. Therefore, the A:P ratio was lower for corn-monensin and higher for control and SBH (Table 2-11).

Increased total VFA concentrations were reported with increasing amounts of SBH (Martin and Hibberd, 1990) or WM (Sunvold et al., 1991) (Table 2-11). In both experiments the molar proportion of acetate decreased but propionate increased with increasing levels of SBH or WM in the diet, consequently the A:P ratio decreased suggesting that microbial fermentation was enhanced. The increased total VFA concentrations, coupled with pH values that did not drop below 6.2, suggest that SBH or WM provide more fermentable substrate for rumen microorganisms than unsupplemented animals.

Ingested feed disappear from rumen through digestion and absorption and through passage. Only the escaping undigested matter passes down to omasum. In this context, the rate of disappearance within the rumen will be the sum

Table 2-11. Effect of byproduct supplementation on VFA.

Reference, forage and type of animal	Total VFA mM	Acetate: Propionate
Heird et al. (1994) (Native grass hay; steers, 161 kg)		
Control	96	3.06
.75 % BW corn-monensin	112	2.12
1.05 % BW SBH	119	2.95
Martin and Hibberd (1990) (Native grass hay; beef cows, 453 kg)		
Control	63.5	5.37
.22 % BW SBH	65.7	5.22
.44 % BW SBH	74.8	4.81
.66 % BW SBH	74.9	4.85
Sunvold et al. (1991) (Bluestem range; steers, 374 kg)		
Control	55.1	5.11
.32 % BW Sorghum-SBM	63.7	4.74
.39 % BW WM	66.5	4.65
.77 % BW WM	75.4	4.10

of the rates of digestion and passage (Van Soest, 1982). An additional indicator of the nutritive value of fibrous feeds for ruminants is their rate of degradation. Small amounts of corn supplementation (.3% BW) increased OM and NDF disappearance from nylon bags incubated in rumen. However, higher amounts of corn in diet decreased both OM and NDF disappearance compared to unsupplemented animals (Sanson and Clanton, 1989; Pordomingo et al., 1991) (Table 2-12).

Summary

From the information presented, it can be concluded that small amounts of concentrate (.3% BW or less) have positive effects on ADG, forage intake and forage digestibility, as well as, rumen conditions for enhanced bacterial activity. Higher amounts of energy supplement produce diverse effects on performance, intake and digestibility of forage and rumen variables that are related to the starch content of the supplement. There is enough evidence to support the contention that soybean hulls and wheat middlings represent an alternative to combinations of corn-soybean meal with the same, or better results in animal performance. In addition, these byproducts have not displayed the detrimental effects on rumen conditions that have been shown for supplements high in starch.

The present study evaluates the effects of low and high levels of different carbohydrate sources (corn-soybean meal,

Table 2-12. Effect of supplementation on forage OM and NDF disappearance.

Reference, forage and type of animal	Forage NDF disappearance % 72 h	Forage OM disappearance, % 72 h	Forage OM disappearance, % 96 h
Sanson and Clanton (1989) (Warm season hay; steers, 418 kg)			
Control	54.7	57.4	NR[a]
.25 % BW whole corn	53.8	60.2	NR
.50 % BW whole corn	47.2	54.5	NR
.75 % BW whole corn	47.7	53.0	NR
Frederickson et al.(1993) (Prairie hay; steers, 194 kg)			
Control	NR	52.2	60.2
Dry rolled corn .32% BW plus urea	NR	58.1	64.9
Pordomingo et al.(1991) (Native rangeland; steers, 507 kg)			
Control	NR	67.9	73.5
.2 % BW whole corn	NR	75.6	77.0
.4 % BW whole corn	NR	66.7	68.1
.6 % BW whole corn	NR	66.0	64.0

[a] NR: not reported.

wheat middlings and soybean hulls) on the hay intake and performance of growing cattle consuming bermudagrass hay. In addition, voluntary intake and total tract digestibility in sheep fed the same concentrate sources and levels will be determined. Finally, effects upon rumen variables produced by feeding the high levels of the same supplements will be evaluated.

It is pertinent to mention that SBH and WM have been used as alternative byproducts in supplementation programs for cattle in the last 20 years. Therefore, more information is needed (particularly in the case of WM where only a few studies have been published when fed to growing cattle), to identify their potential in supplementation programs, and better understand the effects on rumen and total tract digestion when these supplements are fed.

CHAPTER III

EFFECT OF CONCENTRATE SOURCE AND CONCENTRATE LEVEL ON FORAGE INTAKE AND PERFORMANCE OF STEERS AND INTAKE AND TOTAL DIET DIGESTIBILITY OF SHEEP

Introduction

Concentrate supplements have been shown to affect forage intake and utilization. These changes must be predicted to develop a strategic supplementation program which meets the protein and energy needs of growing cattle. This information is required because ruminant productivity on forage-based diets is related, mainly, to voluntary intake (Ernst et al., 1975; Moore, 1981; Holderbaum, 1989; and Ellis et al., 1991), concentration of digestible energy, or a combination of both (Moore, 1981).

These studies were designed to evaluate the effects of different levels of concentrates containing different types of carbohydrates (corn-soybean meal, soybean hulls and wheat middlings) on 1) voluntary intake of forage and performance of growing cattle fed bermudagrass [*Cynodon dactylon* (*L.*)] hay-based diets and 2) voluntary intake and total diet digestibility of sheep fed bermudagrass hay.

Materials and Methods

Hay Intake and Performance Trial with Cattle

Two studies were conducted at the University of Florida Beef Research Unit located in Alachua County, from June 18 to September 10, 1992 (Year 1), and from June 21 to September 6, 1993 (Year 2).

Year 1

Animals. Thirty two crossbred yearlings (24 steers and 8 heifers) of varying Brahman percentages with mean initial full body weight (BW) of 298 kg, were assigned to treatments and pens. Each pen held eight animals. Steers were allotted to three pens (Limousine-sired steers were allotted to one pen while Brangus-sired steers were distributed randomly to two pens), and one pen held all Limousine sired heifers. Pens were equipped with Calan gates (American Calan Inc., Northwood, NH) that allowed measurement of daily hay and concentrate intake by individual cattle. Diets were randomly assigned to cattle. All cattle were dewormed and allotted to pens 3 weeks prior to starting the trial for learning to use the Calan gates. The cattle were fed their assigned diets during this period.

Diets. Bermudagrass hay with a predicted Quality Index (voluntary TDN intake as a multiple of the TDN requirement for maintenance: QI; Moore, 1994) of 1.3 harvested as first growth in June of 1992 was chopped (8 cm approximately) and fed as the base diet. Hay, a complete mineral mix (25% NaCl, 17 to 20% Ca, 6% P, 1% Fe, .5% Zn, .15% Cu, .1% Mg, .06% F, .02% Mn, .01% Co, and .004% Se; Seminole Feed, Ocala, FL.) and water were provided ad libitum.

Treatments were no supplementation (CONTROL), corn-soybean meal (92.5% ground shelled corn, 6.0% soybean meal and 1.5% limestone; CSBM), soybean hulls (ground soybean hulls 100%; SBH), and wheat middlings (93.6% wheat middlings, 5.0% molasses and 1.4% limestone; WM). All three supplements were fed at two levels: approximately 25% (low), and 50% (high) of the total digestible nutrients (TDN): hay TDN + concentrate TDN. Every 14 days, adjustments of concentrate intake were made based on TDN consumption from hay, in order to maintain the targeted TDN percentages.

Calculated TDN intake from hay was considered equivalent to digestible organic matter (DOM) intake (Moore, 1987). Calculation of DOM intake from hays by steers was made by multiplying the OM intake of hays by their OM digestibility. Dry matter and OM digestibility of hays when fed alone to sheep were used to predict OM digestibility for steers. Sheep DM digestibility for each hay was increased by 1.8 percentage units to adjust for differences in DM digestibility between sheep and cattle observed for bermudagrass (Alexander et al., 1962). Steer OM digestibility was predicted from adjusted DM digestibility using the equation from the regression of OM (Y) digestibility on DM (X) digestibility for hays when fed alone to sheep (Allshouse, 1989). The equations expressing this relationshp were:

Year 1: $Y = -3.54 + 1.09\ X$; $r^2 = .97$; RMSE[a] = .61.

Year 2: $Y = 4.36 + .93\ X$; $r^2 = .95$; RMSE = .55.

[a] RMSE: root mean square error

Steer OM digestibilities for hays were estimated to be 53.8 and 54.3% for years 1 and 2, respectively. After the trial was completed, these estimates were used to calculate digestible OM intake of hays fed to steers. Concentration of TDN in supplements was considered 88% for CSBM, 79% for WM and 64% for SBH (NRC, 1984).

Estimation of total digestible OM intake (DOMI) for steers in each treatment was the product of their total OM intake (OM intake from hay plus OM intake from concentrates) and the OM digestibility of each treatment when fed to sheep (Moore, personal communication).

Eight animals were fed the control diet and four animals were supplemented with either CSBM, WM or SBH at the low or high level of supplementation. In each pen two animals were fed the control diet and one animal was fed each of three concentrate sources at both the low or high level of supplementation. Assignment of diets to animals in each pen was at random.

Feeding procedure. Bermudagrass hay was fed twice a day at 0800 and 1500 h and the total daily amount of concentrate was weighed and provided prior to the morning hay feeding. Hay was weighed before each feeding and offered to allow approximately 600 to 775 g of forage refusals (orts). The next day orts were weighed and stored in individual bags for each animal, and every week hay was swept around and under each feeder, weighed and stored in individual bags, different from the orts bags. Weekly hay intake from each animal was estimated as the difference between hay offered, minus orts, minus waste.

Full weights and shrunk weights (animals removed from feed and water for 16 h), were measured on days 1 and 85. Body condition score (BCS) was evaluated on days 0 and 84 using a 1 through 9 condition scoring system with increments of 0.25 (Herd and Sprott, 1986).

Blood samples for plasma urea nitrogen (PUN) analysis were taken on days 0, 28, 56, and 84. Approximately 10 ml of blood were obtained through jugular vein puncture, preserved with heparin (200 units/ml) and stored surrounded with ice while transported to the laboratory. Blood was centrifuged (2500 rpm, 30 minutes), plasma separated and stored frozen (-20 °C) until analyzed.

Sampling procedure and laboratory analysis. Every day while feeding cattle, samples of approximately 300 g of hay given to each pen were taken, and composited every week by pen. Composited hay samples were air dried, mixed and ground to pass a 10.2-cm screen in a hammer mill, and then 4-mm and 1-mm screens in a Wiley mill, and stored in Whirlpak bags until analyzed. Total weekly orts and waste from each animal were air dried, mixed before grinding, then processed and stored as described for hay samples. Concentrates were sampled four times during the trial, ground in a Wiley mill through 4-mm and 1-mm screens and stored until analyzed.

Subsamples of hay offered and concentrates were analyzed for: dry matter (DM) at 105 °C for 18 h in a forced air oven, organic matter (OM) at 550 °C for 6 h in a muffle furnace, nitrogen (N) by aluminum block digestion (Gallaher et al., 1975) and colorimetric analysis, (Technicon, 1978), neutral detergent fiber (NDF) by adding 4 ml of a 2% solution of alpha amylase (Sigma Chemical Co. St. Louis, MO) to concentrates (Goering and Van Soest, 1970; modified by Moore and Foster, 1986) and starch concentration (MacRae and Amstrong, 1968; modified by M. Streeter, 1993). Subsamples of orts plus waste were analyzed for DM and OM as described for hay offered and concentrates.

Plasma samples were analyzed for urea nitrogen concentration by an automated colorimetric procedure (Technicon AutoAnalyzer II Industrial Method no. 339-01, Technicon Instruments Corp., Tarrytown, NY) based on the diacetyl monoxime method of Marsh et al. (1965).

Year 2

Animals. Thirty one steers of varying Brahman percentages with mean initial full body weight of 377 kg, were assigned with respect to breed, treatments and pens. Limousin-sired steers were assigned to two pens and Brangus-sired steers were assigned to two pens. Calan gates (American Calan Inc., Northwood, NH) were used for measurement of daily hay and concentrate intake by individual animals. Animals were dewormed and alloted to pens two weeks prior to starting the trial for training to use the Calan gates. After training animals received their assigned diets. Duration of trial in Year 2 was 77 days.

Diets. Bermudagrass hay with a Quality Index (voluntary TDN intake as a multiple of the TDN requirement for maintenance: QI; Moore, 1994) of 1.5 was harvested as first growth in June of 1993, and was chopped and fed as a base diet. Treatments, feeding procedure, adjustment of concentrate intake, experimental variables, sampling procedures and laboratory analyses were similar to those discussed for Year 1. Concentrates were pelleted in Year 2 to reduce dustiness and facilitate consumption. Composition of concentrates in Year 2 was CSBM: 91.25% ground shelled corn, 6.0% soybean meal, 1.5% limestone and 1.25% molasses; WM: 97.25% wheat middlings, 1.25% molasses and 1.5% calcium carbonate; SBH: 98.75% ground soybean hulls and 1.25% molasses.

Statistical analyses. Data were analyzed statistically using the general linear model (GLM) analysis of variance of the Statistical Analysis System (SAS, 1987). The effects of supplement sources and levels on average daily gain, BCS, PUN, hay intake, substitution rate and forage intake change were analyzed as a factorial design. The mathematical model for partitioning variation in Year 1 was:

$$Y = \mu + T_i + P_j + (TP)_{ij} + E_{ijkl}$$

Where: Y = Variable.
μ = General mean.
T_i= Treatments: control, low and high levels of CSBM, WM or SBH.
P_j= Pen.
Tp_{ij}= Interaction between treatment and pen.
E_{ijkl}= residual error.

All effects were tested using residual error, and preplanned orthogonal contrasts were used for means separation. Orthogonal contrasts were designed to measure effects of supplementation (Control vs supplementation), level (low and high TDN from concentrates) of supplementation and source of carbohydrates in supplements. Contrasts of WM vs CSBM and SBH allowed comparison of the higher concentration of CP in supplement (WM) to the lower concentrations of CP in the supplement (CSBM and SBH). Contrasts of CSBM vs SBH allowed comparison of high vs low level of starch in supplements. Contrasts of WM vs CSBM and SBH by level evaluated if different concentrations of CP gave similar (interaction not significant) or different (interaction significant) results at the low and high levels of supplementation. Contrast comparing CSBM vs SBH by level of supplementation evaluated if the effects of source and amount of starch were similar or different at the low and high levels of supplementation (Table 3-1). In Year 2, the mathematical model and the preplanned orthogonal contrasts used were the same as in Year 1.

Intake and Digestibility Trial with Sheep.

Two digestibility trials were conducted at the University of Florida Nutrition Laboratory in Gainesville, from October 1 to November 18, 1992 (Year 1), and from September 20 to November 7, 1993 (Year 2), using hay and concentrates similar to that fed in the corresponding intake and performance trial with cattle.

Animals and diets. Twenty-four mature wethers (47.4 kg BW in Year 1, and 60.0 Kg BW in Year 2) in a partially balanced incomplete block design (balanced for concentrate source and concentrate level), were used in each digestibility trial which consisted of two periods. In both periods, each sheep received the same hay and remained in the same pen, but was offered a different concentrate source and concentrate level. This design allowed six observations per concentrate source and level, and twelve observations for the control each year.

Prior to the experiment, sheep were shorn and treated with Ivermectin to control internal parasites. At the start of each period all sheep were fitted with canvas fecal

Table 3-1. Planned orthogonal contrasts used in the analysis of intake and performance trial with cattle and total diet digestibility with sheep.

	Treatments						
		LOW			HIGH		
Contrast	CONTROL	CSBM	WM	SBH	CSBM	WM	SBH
Control vs suppl.	6	-1	-1	-1	-1	-1	-1
Low vs high level	0	-1	-1	-1	1	1	1
WM vs CSBM&SBH	0	-1	2	-1	-1	2	-1
CSBM vs SBH	0	-1	0	1	-1	0	1
WM vs CSBM&SBH/level	0	1	-2	1	-1	2	-1
CSBM vs SBH/level	0	1	0	-1	-1	0	1

collection bags and placed in individual metabolism cages with slatted wooden floors. Each period consisted of a 14 day preliminary phase, followed by a 7 day collection phase for the determination of voluntary hay intake and nutrient digestibility. Water, and trace mineralized salt were available ad libitum. At the end of each period sheep were weighed.

Feeding procedure and sampling. Hay was chopped using a WIC chopper (Wickman, Inc., Johnson, QUE, Canada) to approximately 8 cm and fed ad libitum. Amount of hay offered was determined by adjusting the quantity offered daily to provide between 150 and 300 g of orts each day. If total orts were between 0 and 50 g, or 50 and 150 g for a given day, the amount of hay offered was increased by 200 or 100 g, respectively. If on three consecutive days, the amount of daily orts exceeded 300 g, the amount of hay offered was decreased by 100 g.

Supplements were offered once daily between the collection of orts and the feeding of hay. Amount of supplement fed was adjusted twice during the preliminary phase to provide the targeted 25 or 50% of the total TDN intake from the concentrate source. Daily supplement intake was fixed during the collection phase.

During collection phases, a representative sample of the hay offered was taken daily to provide approximately 2 kg of total sample for each sheep. Because the amount of hay offered often changed, the same percentage sample was taken each day to avoid bias in sampling. The amount of hay weighed out was the sum of the amount to be offered plus the amount of sample to be taken. Grab samples were then obtained, placed in double plastic garbage bags, and sealed. All daily samples from a given sheep were placed in the same bag. The total weight of the hay sampled was recorded prior to grinding. Samples of supplement were obtained daily, and placed in paper bags.

Orts were collected prior to each feeding on days one through seven of the collection phase. Feeders were swept out, orts collected and transferred to paper bags, weight of orts was recorded prior to grinding. Waste was designated as any feed which was pulled from the feeder but not consumed by the sheep. Screens were placed under the cages on Day 1 of the collection phase and the waste was allowed to accumulate until the end of the collection phase, when total collection was made. Waste was placed in paper bags, and if the amount collected exceeded 70 g, the waste was dried in a forced air oven at 60 °C, for 48 hours.

Feces were collected and sampled after feeding concentrates and hay to sheep, starting on Day 2 through Day 8 of the collection phase. Total daily feces voided were collected in a tared plastic bucket, weighed and mixed. A 20% representative aliquot was placed in a paper bag and dried in a forced air oven at 60 °C, for 48 hours.

At the end of the collection phase, samples of hay concentrates, orts, waste, and feces were allowed to equilibrate at room temperature for at least 2 Days. Samples were composited by sheep. Hay, orts, and waste samples were ground through a 10.2-cm screen in a hammer mill (Smalley Mfg., Manitoc, WI) and stored in plastic bags. Samples were well mixed and a 500-g subsample obtained. Hay, supplement, orts, waste and feces samples were ground through a 4-mm screen of a Wiley mill. These samples were well mixed and a 200-g subsample was obtained and reground through a 1-mm screen of a Wiley mill and placed in Whirlpak bags until analyzed for DM, OM, and NDF. Samples of hay offered and concentrates were analyzed for CP, ADF, lignin and starch as described in the intake and performance trial with steers.

Voluntary intake and digestion coefficients of OM and NDF were estimated using the daily DM offered (hay plus concentrate), daily DM of orts, daily DM of waste and daily DM of feces, along with their respective OM and NDF composition, expressed on a DM basis (Moore, 1981). For example, the digestibility coefficient of OM was estimated as follows:

Organic matter intake (OMI) = OM hay - OM orts - OM waste
Digestible OMI (DOMI) = OMI - OM feces
Organic matter digestibility (OMD) = DOMI / OMI

Statistical analyses. Data were analyzed using the general linear model (GLM) analysis of variance of the Statistical Analysis System (SAS, 1987). The mathematical model for analysis of voluntary intake of hay and digestibility was:

$$Y= \mu + T_i + P_j + (TP)_{ij} + E_{ijk}$$

Where: Y = Variable.
μ = General mean.
T_i= Treatments: control, low and high levels of CSBM, WM or SBH.
P_j= Periods.
TP_{ij}= Interaction between treatment and period.
E_{ijk}= residual error.

Orthogonal contrasts used to compare mean differences were identical to those used in the intake and performance trial with steers (Table 3-1).

Results and Discussion

Intake and Performance Trial with Cattle

Statistical analyses of data were performed according to sources of variation present during trials: pens, treatments and years. There was no interaction between treatments and pens for either year when years were analyzed separately. Analysis of data combined for both years showed no interactions between treatment and pen, treatment and year, and treatment and year and pen. Because there were no interactions with year, discussion of results will be combined for both years.

Average of coefficients of variation (standard deviation divided by the mean: CV; Steel and Torrie, 1960) for shrunk weights was lower than average of CV for full weights: 27.1% for shrunk weights and 29.4% for full, respectively (Table 3-2). This difference in CV between full and shrunk weights suggested variations in fill. Therefore, weight gain discussions will be limited to shrunk daily gains. In addition, Hughes (1976) suggested that fasting before weighing partially adjusted for degree of fill between animals receiving different kinds of feed.

Chemical composition of bermudagrass hay and concentrates fed to steers in years 1 and 2 appear in Tables 3-3 and 3-4. Differences in structural (NDF) and nonstructural carbohydrates (starch) are evident among supplements. The starch concentration of CSBM is the highest among concentrates, and lowest for SBH (64.7, 27.4 and 4.4% for CSBM, WM and SBH, respectively). However, the NDF concentration is the lowest for CSBM and highest for SBH (15.4, 38.7 and 59.8% for CSBM, WM and SBH, respectively). Wheat middlings have intermediate concentrations of starch and NDF. The CP concentration of hay was lower by nearly 2 percentage units in Year 1 (9.6%), as compared to Year 2 (11.4%) and higher in NDF concentration (83.5 vs 77.6% for years 1 and 2, respectively).

Calculated TDN intake from concentrates was similar to the targeted (25%) TDN at the low level of supplementation

Table 3-2. Coefficient of variation (%) for full and shrunk weights of cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM) or soybean hulls (SBH) (1992-1993).[a]

	Treatments						
		Low			High		
	Control	CSBM	WM	SBH	CSBM	WM	SBH
Full ADG							
Mean	.35	.63	.68	.63	.77	.98	1.05
SD[b]	.23	.22	.18	.20	.18	.13	.11
CV[c]	65.7	34.9	26.4	31.7	23.4	13.3	10.5
Shrunk ADG							
Mean	.30	.63	.65	.61	.76	.90	.95
SD	.18	.19	.17	.17	.18	.11	.09
CV	60.0	30.2	26.2	27.9	23.7	12.2	9.5

[a] Values correspond to average of both years.
[b] SD: standard deviation.
[c] CV: coefficient of variation (SD / Mean).

Table 3-3. Chemical composition of bermudagrass hay and concentrates fed to steers and heifers (Year 1).

Item	Bermudagrass hay	CSBM[a]	WM[b]	SBH[c]
Dry matter, %	90.2	88.5	89.5	90.3
		% DM basis		
Organic matter	95.6	96.5	91.8	93.6
Crude protein	9.6	12.4	19.9	15.8
Neutral detergent fiber	83.5	15.9	39.5	58.9
Acid detergent fiber	41.7	3.0	12.7	47.5
Lignin	5.4	0.3	3.4	1.3
Starch	5.0	66.1	28.3	3.6

[a] CSBM: 92.5% ground shelled corn, 6.0% soybean meal and 1.5% limestone.

[b] WM: 93.6% wheat middlings, 5.0% molasses and 1.4% limestone.

[c] SBH: ground soybean hulls 100%.

Table 3-4. Chemical composition of bermudagrass hay and concentrates fed to steers (Year 2).

Item	Bermudagrass hay	CSBM[a]	WM[b]	SBH[c]
Dry matter, %	90.8	89.5	89.0	89.0
		% DM basis		
Organic matter	93.8	93.7	92.7	95.1
Crude protein	11.4	12.6	18.5	12.4
Neutral detergent fiber	77.6	14.8	37.8	60.7
Acid detergent fiber	40.5	6.3	13.1	51.2
Lignin	5.1	0.9	3.7	1.5
Starch	4.2	63.2	26.4	5.1

[a] Pelleted CSBM: 91.25% ground shelled corn, 6.0% soybean meal, 1.5% limestone, and 1.25 molasses.

[b] Pelleted WM: 97.25% wheat middlings, 1.25% molasses and 1.5% calcium carbonate.

[c] Pelleted SBH: 98.75% ground soybean hulls and 1.25 molasses.

(24.6 and 23.8% for years 1 and 2, respectively). However, at the high level of supplementation calculated TDN intake was lower than the targeted TDN (46.7 and 44.3 for years 1 and 2, respectively) (Table 3-5). Intake of TDN by animal, treatment and year appear in Table A3-1.

Table 3-5. Calculated TDN intake from concentrates, as percent of total TDN intake, by cattle fed bermudagrass hay and supplemented with corn-soybean (CSBM), wheat middlings (WM) or soybean hulls (SBH).

		Treatments					
		Low			High		
	Control	CSBM	WM	SBH	CSBM	WM	SBH
Year 1	---	25.2	25.0	23.5	48.5	46.5	45.2
Year 2	---	23.6	24.2	23.6	45.0	46.7	41.3

Concentrate supplements fed to cattle receiving bermudagrass hay ad libitum increased weight gains (Table 3-6). Shrunk daily gain (ADG) was higher ($P=.0001$) for cattle fed supplemental concentrates (.75 kg d^{-1}) compared to unsupplemented cattle (.30 kg d^{-1}).

Comparison across levels showed higher ADG ($P=.0001$) for the high than the low level of supplementation (.87 kg d^{-1} and .63 kg d^{-1} for the high and low levels of supplementation). Comparison of ADG between CSBM and SBH showed a treatment by level interaction ($P=.06$) with no difference at the low level, but higher ADG for SBH (.95 kg

Table 3-6. Performance by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM) or soybean hulls (SBH) in 1992 and 1993.

		Daily gain, kg		
Source	Level	Full	Shrunk	BCS[a] Change
CONTROL	0	.35	.30	-.57
CSBM	Low	.63	.63	.65
WM	Low	.68	.65	-.23
SBH	Low	.63	.61	.23
CSBM	High	.77	.76	.34
WM	High	.98	.90	.13
SBH	High	1.05	.95	.61
SEM[b]				
CONTROL		.05	.04	.17
CONCENTRATES		.07	.06	.23
CONTRASTS, (P value)				
Control vs suppl.		.0001	.0001	.0001
Low vs high level		.0001	.0001	.45
WM vs CSBM&SBH		.32	.45	.01
CSBM vs SBH		.04	.15	.75
WM vs CSBM&SBH/level		.94	.87	.44
CSBM vs SBH/level		.04	.06	.06

[a] BCS: body condition score.
[b] SEM: standard error of the mean.

d^{-1}) than CSBM (.76 kg d^{-1}) at the high level of supplementation (Table 3-6).

Differences in ADG between CSBM and SBH do not agree with Hsu et al. (1987), Anderson et al. (1988a), Klopfenstein and Owen (1988), Brown and Weigel (1993), Poore (1993), and Martin and Hibberd (1990). They reported similar ADG between these concentrate sources when fed at comparable amounts to those at the high level of supplementation in this research.

The lower ADG for CSBM at the high level of supplementation may be related to modifications of rumen environment caused by larger quantities of starch. Corn consumption at levels of .4 and .6% BW have been shown to decrease forage intake, particulate and liquid passage rates and OM degradation of forage (Pordomingo et al., 1991), and reduce rumen pH, ammonia concentrations and NDF disappearance compared to unsupplemented cattle (Chan et al., 1991). These factors combined with low intake of total crude protein (1.05 kg d^{-1}) resulted in low ADG for this treatment. On the other hand, higher ADG at the high level of SBH supplementation compared to the high level of CSBM, may be attributable to the digestible NDF intake present in SBH.

Body condition score was affected by concentrates. Unsupplemented animals lost more (P=.0001) body condition (.86 difference in BCS), compared to supplemented animals.

Supplemented cattle lost less or increased their BCS (-.23 to .65) (Table 3-6). Level of supplementation (low versus high) had no effect (P=.45) on BCS.

Comparisons between sources showed differences in BCS. Cattle supplemented with WM lost BCS (-.05) but cattle supplemented with CSBM or SBH gained BCS (.46) (Table 3-6).

There was a treatment by level interaction (P=.06) in BCS change when CSBM was compared to SBH. At the low level of supplementation CSBM had higher BCS change (.65) than SBH (.23), but at the high level of supplementation CSBM had lower (.34) BCS change than SBH (.61) (Table 3-6). In spite of these differences, changes in BCS generally reflected changes in body weight for CSBM and SBH.

The response in BCS does not agree with Poore (1993) who fed Angus heifers (205 kg) diets based on sorghum silage and supplemented with corn, wheat middlings, or soybean hulls plus soybean meal in all diets. He reported similar gains for cattle fed corn, WM or SBH (1.00, .91 and 1.00 kg d^{-1} respectively), as well as a similar gain in body condition.

A similar ADG for WM compared to SBH, but a decreased BCS in WM compared to CSBM and SBH suggests variations in the efficiency of utilizing the energy released during digestion; specifically, the lower BCS for growing cattle supplemented with WM suggests a decreased fat deposition compared to cattle supplemented with CSBM or SBH.

Differences in proportions of volatile fatty acids (Blaxter, 1962; Minson, 1990), particularly the higher proportion of acetic acid and the lower proportion of propionic acid in the digestion products, has been suggested to reduce the efficiency of body fat synthesis. In addition, Minson (1990) remarked that acetic and butyric acids can only be used for fattening with high efficiency if there is an adequate supply of propionate or glucose.

Another possible explanation for differences in BCS change may be related to the concentrations of arginine entering the duodenum. Arginine has been reported to increase N retention and somatotropin (STH) secretion which could result in increased lean growth and reduced fat deposition (Davenport et al., 1990).

Arginine reaching duodenum was estimated using tabulated values for arginine in concentrates (Macgregor et al., 1978) and assuming the percentage of bypass arginine was the same as percentage for bypass protein (Preston, 1987) for each supplement. Daily arginine calculated to reach the duodenum was 3.5, 6.9 and 1.0 g (DM basis) for the low levels, and 8.4, 15.2 and 2.2 g for the high levels of CSBM, WM and SBH respectively in Year 1. For Year 2, estimated daily arginine calculated to reach the duodenum was: 4.1, 9.0 and 1.2 g for the low levels, and 9.4, 20.0 and 2.5 g for the high levels of CSBM, WM and SBH, respectively.

Concentrations of PUN have been used as an indicator of the protein to energy ratio in the diet and reflect the adequacy of protein in the diet (Hammond, 1992). There was a year by treatment interaction (P=.01) in PUN due to low concentrations of PUN at the high level of CSBM supplementation in Year 1 (6.9 mg dL^{-1}) (Table 3-7). However, in Year 2 PUN for CSBM was similar (10.6 mg dL^{-1}) to SBH at both levels of supplementation, but lower than WM (12.9 and 17.6 mg dL^{-1} for low and high levels of WM supplementation) (Table 3-7). The low ADG for CSBM at the high level was reflected in the low PUN in growing cattle fed this treatment.

In Year 2, PUN for cattle supplemented with WM was higher (P=.02) at both levels of supplementation, as compared with cattle supplemented with CSBM or SBH (12.9 vs 10.5 mg dL^{-1} for WM and combined data of CSBM and SBH at the low level, and 17.6 vs 10.7 mg dL^{-1} for WM and combined data for CSBM and SBH at the high level; Table 3-7). This higher PUN value may be attributed to the higher CP intake by steers fed WM for both levels of supplementation.

In both years, with the exception of CSBM at the high level of supplementation in Year 1, values of PUN were within the recommended levels of 11 and 15 mg dL^{-1} usually associated with good performance for growing cattle (Byers and Moxon, 1980).

Table 3-7. Plasma urea nitrogen (PUN) in growing cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH).

		Year 1	Year 2
Source	Level	PUN, mg dL^{-1}	PUN, mg dL^{-1}
CONTROL	0	12.1	12.9
CSBM	Low	10.3	10.5
WM	Low	12.7	12.9
SBH	Low	12.6	10.4
CSBM	High	6.9	10.6
WM	High	14.5	17.6
SBH	High	13.3	10.8
SEM			
CONTROL		.62	.84
CONCENTRATES		.88	1.19
CONTRASTS, (P value)			
Control vs suppl.		.57	.45
Low vs high level		.66	.06
WM vs CSBM&SBH		.001	.0001
CSBM vs SBH		.0001	.94
WM vs CSBM&SBH/level		.05	.02
CSBM vs SBH/level		.02	.91

Voluntary intake of hay as percentage of body weight (HAYPBW) was affected by supplementation (Table 3-8). Consumption of hay was lower (P=.002) in supplemented (1.78% BW) than in control (1.99% BW) cattle. Voluntary hay intake was lower (P=.0001) in the high (1.63% BW) than the low (1.93% BW) level of supplementation. Comparisons across concentrate sources showed no difference in HAYPBW (Table 3-8). Intake in kg d^{-1} by cattle in years 1 and 2 appear in Tables A3-2 and A3-3.

The decrease in intake with increasing levels of all concentrates agrees with Chase and Hibberd (1987), who recorded a decrease in hay intake when corn was fed at increasing levels (.23%, .46%, and .69% BW). It also agrees with reports from Brown and Weigel (1993), who reported that hay intake was reduced with increasing levels of corn or SBH.

A decrease in hay intake was recorded in Year 1 (Table 3-9) for the low levels of CSBM and WM. In contrast, hay intake in Year 2 (Table 3-10) was slightly higher for CSBM and WM at the low level of supplementation than unsupplemented cattle (1.94, 1.96 and 1.80% BW for CSBM, WM and CONTROL, respectively).

The higher hay intake in Year 2, agrees with the statement that low levels of supplementation of feedstuffs high in starch may have little effect on digestion, because small changes in ruminal conditions avoid large shifts in

Table 3-8. Intake (% BW) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in 1992 and 1993.

		Intake (% BW, DM Basis)			OM Intake, KG d^{-1}				
Source	Level	Suppl	Hay	Total	Total	DOMI	Feed efficiency[a]	SR[b]	FIC[c]
CONTROL	0	---	1.99	1.99	5.79	3.03	60.7	---	---
CSBM	Low	0.38	1.95	2.33	7.21	4.15	12.3	-0.11	-0.04
WM	Low	0.43	1.98	2.41	7.91	4.33	12.7	-0.02	-0.01
SBH	Low	0.48	1.87	2.35	7.70	4.40	13.5	-0.04	-0.02
CSBM	High	0.83	1.59	2.42	8.04	5.03	11.0	-0.48	-0.40
WM	High	0.96	1.65	2.61	8.59	4.89	9.6	-0.35	-0.34
SBH	High	1.04	1.65	2.69	8.74	5.46	9.2	-0.33	-0.34
SEM									
CONTROL		-	0.06	0.06	.26	.15	15.6	-	-
CONCENTRATES		0.02	0.08	0.08	.36	.20	21.4	0.19	0.11
CONTRASTS, (P value)									
Control vs Suppl.		---	.002	.0001	.0001	.0001	.007	---	---
Low vs high level		.0001	.0001	.002	.006	.0001	.87	0.05	.0002
WM vs CSBM&SBH		0.59	0.43	0.35	.30	.39	.98	0.68	0.73
CSBM vs SBH		.0001	0.91	0.08	.10	.09	.99	0.73	0.72
WM vs CSBM&SBH/level		0.57	0.78	0.92	.67	.24	.99	0.78	0.85
CSBM vs SBH/level		0.08	0.35	0.14	.76	.65	.94	0.35	0.36

[a] DOMI / shrunk ADG.
[b] SR: substitution rate = decrease in forage intake per unit of supplement fed.
[c] FIC: forage intake change = forage intake with supplement - forage intake when fed alone.

Table 3-9. Intake (% BW) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hull (SBH) in Year 1.

		Intake (% BW, DM Basis)			OM Intake, KG d^{-1}				
Source	Level	Suppl	Hay	Total	Total	DOMI	Feed efficiency[a]	SR[b]	FIC[c]
CONTROL	0	---	2.15	2.15	5.51	2.86	95.1	---	---
CSBM	Low	0.38	1.95	2.33	6.50	3.73	13.6	-.53	-.20
WM	Low	0.42	2.00	2.42	6.88	3.81	13.7	-.36	-.15
SBH	Low	0.49	1.97	2.46	7.25	4.23	13.6	-.37	-.18
CSBM	High	0.86	1.60	2.46	7.43	4.69	9.8	-.64	-.55
WM	High	0.94	1.69	2.63	7.60	4.34	8.2	-.49	-.46
SBH	High	1.07	1.59	2.66	7.93	5.06	8.6	-.52	-.56
SEM									
CONTROL		-	.07	.09	.26	.16	30.1	-	-
CONCENTRATES		.04	.10	.13	.37	.22	42.7	.27	.14
CONTRASTS, (P value)									
Control vs suppl.		---	.0004	.003	.0001	.0001	.02	---	---
Low vs high level		.0001	.0004	.09	.01	.0002	.89	0.39	.0001
WM vs CSBM&SBH		.74	.47	.65	.89	.07	.99	0.95	.73
CSBM vs SBH		.005	.98	.22	.10	.06	.98	0.59	.89
WM vs CSBM&SBH/level		.96	.74	.82	.89	.39	.98	0.42	.22
CSBM vs SBH/level		.35	.91	.78	.73	.77	.98	0.47	.43

[a] DOMI / shrunk ADG.
[b] SR: substitution rate = decrease in forage intake per unit of supplement fed.
[c] FIC: forage intake change = forage intake with supplement - forage intake when fed alone.

Table 3-10. Intake (% BW) by cattle fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hull (SBH) in Year 2.

		Intake (% BW, DM Basis)			OM Intake KG d^{-1}				
Source	Level	Suppl	Hay	Total	Total	DOMI	Feed efficiency[a]	SR[b]	FIC[c]
CONTROL	0	---	1.80	1.80	6.12	3.22	21.3	---	---
CSBM	Low	0.38	1.94	2.32	7.92	4.57	10.9	.37	.14
WM	Low	0.43	1.96	2.39	8.96	4.86	11.7	.37	.16
SBH	Low	0.47	1.76	2.23	8.15	4.57	13.4	-.09	-.04
CSBM	High	0.81	1.57	2.38	8.65	5.36	12.2	-.28	-.23
WM	High	0.98	1.61	2.59	9.58	5.43	11.0	-.19	-.19
SBH	High	1.01	1.71	2.72	9.56	5.85	9.9	-.09	-.09
SEM									
CONTROL		-	.08	.07	.29	.16	4.0	-	-
CONCENTRATES		.03	.11	.09	.38	.22	5.3	.30	.20
CONTRASTS, (P value)									
Control vs suppl.		---	.62	.0001	.0001	.0001	.04	---	---
Low vs high level		.0001	.0007	.003	.006	.0001	.81	.01	.01
WM vs CSBM&SBH		.19	.65	.32	.04	.77	.96	.43	.31
CSBM vs SBH		.0005	.86	.18	.14	.26	.98	.14	.63
WM vs CSBM&SBH/level		.32	.46	.64	.50	.23	.96	.52	.28
CSBM vs SBH/level		.13	.15	.15	.37	.26	.65	.005	.01

[a] DOMI / shrunk ADG.
[b] SR: Substitution rate= decrease in forage intake per unit of supplement fed.
[c] FIC: forage intake change = forage intake with supplement - forage intake when fed alone.

fiber-digesting bacteria and thus may promote forage intake (Frederickson et al., 1993; Pordomingo et al., 1991; Galloway et al., 1991; Chan et al., 1991). This response may reflect differences in forage characteristics and the resulting ruminal conditions that controlled voluntary intake of hay.

Hay intake (% BW) in Year 1 and Year 2 (Tables 3-9 and 3-10) for unsupplemented cattle was dissimilar (2.15% BW for Year 1 vs 1.80% BW for Year 2). However, the higher consumption of hay in Year 1 produced lower ADG than the hay consumed in Year 2 (.21 d^{-1} for Year 1 vs .42 kg d^{-1} for Year 2). These results may reflect a higher quality for the hay offered in Year 2, which contained more CP (9.6% vs 11.4% for years 1 and 2), and less NDF (83.5% vs 77.6% for years 1 and 2 respectively; Tables 3-3 and 3-4).

Total intake (hay intake plus concentrate intake) was higher (P=.0001) in supplemented (2.47% BW) than unsupplemented (1.99% BW) cattle, and the high level of supplementation recorded higher (P=.002) total intake than the low level of supplementation (2.57% BW vs 2.36% BW for the high and low level of supplementation, respectively). Comparisons across concentrate sources showed higher (P=.08) total intake for SBH (2.53 % BW) than CSBM supplemented cattle (2.38% BW) (Table 3-8).

Digestible OMI (total OMI x OMD) was higher (P=.0001) for supplemented cattle (3.0 vs 4.7 kg d^{-1} for control and supplemented cattle), and higher (P=.0001) in the high than the low level of supplementation (4.3 vs 5.1 kg d^{-1} for low and high feeding levels). In addition, SBH supplemented cattle had higher (P=.09) DOMI than CSBM supplemented cattle (4.6 vs 4.9 for CSBM and SBH, respectively) (Table 3-8).

Feed efficiency (DOMI / shrunk ADG) was better (P=.007) for supplemented than control cattle (11.4 vs 60.7 kg of DOMI for each kg of weight gain). There were no differences in feed efficiency due to level or concentrate source (Table 3-8).

Forage intake change (FIC) as percentage of body weight, defined as the observed forage intake when fed with supplement minus the forage intake when fed alone (Moore, 1992), was affected by level of supplementation (P=.0002) (Table 3-8). Positive and negative values for FIC were recorded (Tables 3-9 and 3-10). Negative values for FIC mean that less forage was consumed when supplemented than when fed alone, and positive FIC means that forage intake was increased due to supplementation (Brant, 1993).

In Year 2 an interaction (P=.005) in FIC was recorded between CSBM and SBH by level of supplementation (Table 3-10). For the low level of supplementation, CSBM had a positive FIC (.14) while the FIC for SBH was negative (-.04). For the high level of supplementation, FIC was more negative for CSBM (-.23) than SBH (-.09). This response, may reflect poorer conditions in the rumen (e.g., lower pH) that may lower forage intake. Values of FIC recorded in these trials ranged from .16 to -.56 and are in agreement with values reported by Moore (1992) for supplementation of bermudagrass-based diets (Tables 3-8, 3-9 and 3-10).

Substitution rate (SR), defined as the decrease in forage intake (% BW) per unit of supplement fed (Moore, 1992; Brant, 1993), was affected by level of supplementation (P=.05) (Table 3-8). This result was due to the positive hay intake recorded for CSBM and WM at the low level of supplementation in Year 2 (Table 3-10). The substitution rate for CSBM and SBH by level of supplementation in Year 2, responded similarly as FIC. Positive SR for CSBM fed at the low level (.37) and negative SR for SBH (-.09) were accompanied by higher (-.28) substitution rates in CSBM fed at the high level and lower SR for SBH (-.09) (Table 3-10).

Plot of total DOMI (TDOMI) and ADG (Figure 3-1) shows that at the low feeding level all three concentrates sources produced similar ADG. However, at the high feeding level SBH supplemented cattle had higher TDOMI and their ADG was also higher than CSBM and WM. At the high feeding level CSBM and WM had similar TDOMI (Table 3-8), but ADG for WM supplemented cattle was higher than CSBM supplemented cattle (Table 3-8; Figure 3-1).

Higher TDOMI and ADG in SBH supplemented cattle may be related to less negative associative effects produced by this supplement. It is possible that NDF digestibility of

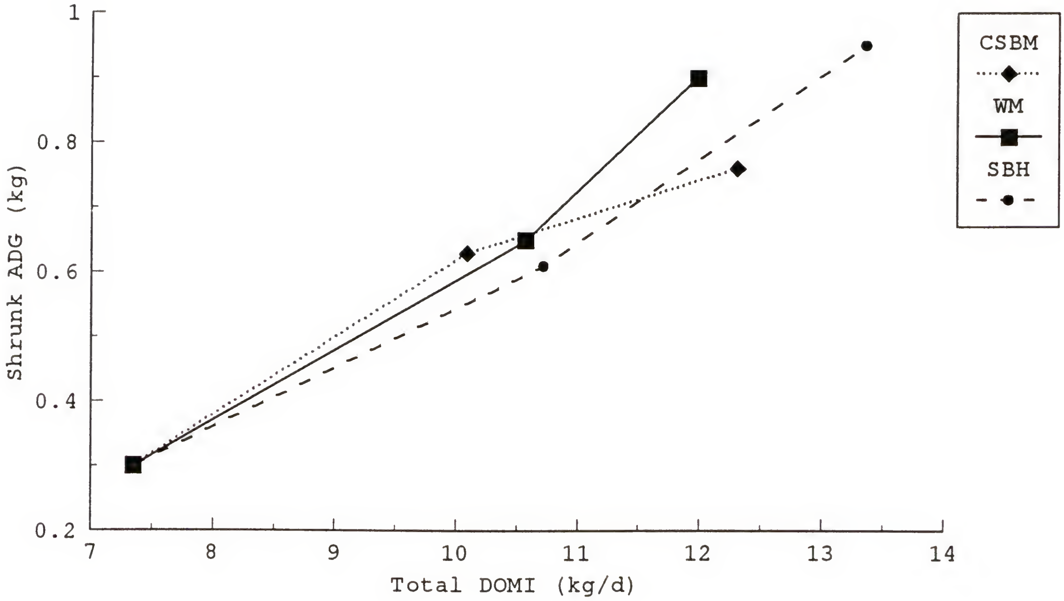

Figure 3-1. Total digestible organic matter intake (DOMI) and shrunk average daily gain (ADG) for different supplement levels and sources (corn-soybean meal, CSBM; wheat middlings, WM and soybean hulls, SBH).

SBH improves total diet NDF digestibility and thus, increases total intake. In addition, rumen conditions (e.g., pH, total VFA production, ammonia N, rates of passage) may be improved in cattle supplemented with SBH. Higher ADG in WM supplemented cattle, as compared to CSBM supplemented cattle, with the same TDOMI in both treatments suggests differences in nutrient utilization.

Voluntary Intake and Total Tract Digestibility with Sheep

Statistical analyses detected no interactions between treatments and periods when analyzed each year. Analysis of data combined for both years revealed no interaction between treatments and periods, treatments and years, and treatments and years and periods. Because there were no interactions with Year, as was the case in the performance and intake trial with cattle, discussion of results will be based on differences found on the analysis of data combined for both years.

Chemical composition of bermudagrass hay and concentrates fed to sheep in Years 1 and 2 appear in Tables 3-11 and 3-12.

Total organic matter intake (OMI) was affected by supplementation (Table 3-13). Unsupplemented sheep consumed lower ($P=.0001$) amounts of total OM than supplemented sheep (1011 vs 1214.7 g d^{-1} for control ans supplemented sheep, respectively; Table 3-13). Total OM intake was not affected

Table 3-11. Chemical composition of bermudagrass hay and concentrates fed to sheep (Year 1).

Item	Bermudagrass hay	CSBM[a]	WM[b]	SBH[c]
Dry matter, %	90.2	89.5	89.0	89.5
		% DM basis		
Organic matter	95.3	94.0	92.7	95.1
Crude protein	11.3	12.1	20.0	15.1
Neutral detergent fiber	81.4	14.8	37.8	60.7
Acid detergent fiber	39.6	4.6	14.2	55.5
Lignin	5.9	0.8	4.1	1.9
Starch	5.0	65.3	27.5	4.5

[a] CSBM: 92.5% ground shelled corn, 6.0% soybean meal and 1.5% limestone.

[b] WM: 93.6% wheat middlings, 5.0% molasses and 1.4% limestone.

[c] SBH: ground soybean hulls 100%.

Table 3-12. Chemical composition of bermudagrass hay and concentrates fed to sheep (Year 2).

Item	Bermudagrass hay	CSBM[a]	WM[b]	SBH[c]
Dry matter, %	89.8	89.5	89.2	89.5
		% DM basis		
Organic matter	93.8	93.7	92.2	94.3
Crude protein	10.6	12.2	18.9	12.1
Neutral detergent fiber	80.7	15.3	37.5	61.9
Acid detergent fiber	42.1	6.4	12.8	49.9
Lignin	5.4	0.9	3.5	1.6
Starch	4.2	64.7	26.4	4.9

[a] Pelleted CSBM: 91.25% ground shelled corn, 6.0% soybean meal, 1.5% limestone and 1.25 molasses.

[b] Pelleted WM: 97.25% wheat middlings, 1.25% molasses and 1.5% calcium carbonate.

[c] Pelleted SBH: 98.75% ground soybean hulls and 1.25 molasses.

Table 3-13. Total tract organic matter digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) (1992-1993).

		Organic matter intake g d^{-1}					
Source	Level	Hay	Suppl	Total	Feces, g d^{-1}	Digestible OMI g d^{-1}	OMD, %
CONTROL	0	1011	0	1011	481	530	52.3
CSBM	Low	977	194	1171	499	672	57.4
WM	Low	945	204	1149	520	629	54.8
SBH	Low	968	265	1233	529	704	57.2
CSBM	High	806	460	1266	474	792	62.6
WM	High	743	433	1176	505	671	56.9
SBH	High	763	530	1293	485	808	62.5
SEM							
CONTROL		32	-	38	17	22	0.5
CONCENTRATES		45	16	54	24	32	0.7
CONTRASTS, (P value)							
Control vs suppl.		.0002	.0001	.0001	.30	.0001	.0001
Low vs high level		.0001	.0001	.17	.16	.001	.0001
WM vs CSBM&SBH		.38	.001	.09	.46	.001	.0001
CSBM vs SBH		.56	.0001	.41	.41	.44	.86
WM vs CSBM&SBH/level		.86	.17	.59	.65	.21	.01
CSBM vs SBH/level		.70	.98	.74	.70	.79	.91

by level of supplementation (P=.17) or by supplement source when combined across years (Table 3-13).

Digestible OM intake (DOMI) was affected by supplementation, level of supplement and type of supplement fed. Lower (P=.0001) DOMI was recorded in control animals (530 g) than in supplemented sheep (713 g). Similarly, lower (p=.001) DOMI was displayed in the low (668 g) than the high level (757 g) of supplementation. Comparison across concentrate sources showed lower (P=.001) DOMI for WM (650 g) than CSBM and SBH (744 g) when averaged across both levels of supplementation (Table 3-13).

Organic matter digestibility (OMD) was affected by supplementation, level and type of concentrate offered (Table 3-13). Digestion of OM in supplemented animals was higher (P=.0001) than unsupplemented sheep (58.6% vs 52.3%), and was higher (P=.0001) in the high (60.7%) than the low (56.5%) level of supplementation. Comparison between sources of concentrate showed lower (P=.0001) OMD for WM when compared with CSBM and SBH at both levels (55.9% for WM and 59.9% for combined data of CSBM and SBH, respectively). Similar trends occurred when WM was compared to CSBM and SBH at different levels, OMD was 54.8% for WM compared to 57.3% for data combined of CSBM and SBH in the low level, and 56.9% for WM vs 62.6% for data combined of CSBM and SBH in the high level of supplementation, respectively (P=.01) (Table 3-13).

The hay NDF intake (NDF of hay, minus NDF of orts, minus NDF of waste; NDFI) was affected by supplementation (P=.0003) and by level of supplementation (.0001) (Table 3-14). Total NDF intake (hay NDFI + concentrate NDFI) was affected by level of supplementation (P=.08), and by concentrates. Total NDF intake was higher (P=.0001) for SBH than CSBM supplemented cattle (1015 vs 806 g d^{-1} for SBH and CSBM, respectively).

The digestible NDFI (NDFI minus NDF in feces; DNDFI) was not affected (P=.31) by supplementation or by level of supplementation (P=.14). The DNDFI showed an interaction (P=.006) when CSBM was compared to SBH at the two levels of supplementation. The DNDFI decreased with increasing levels of supplementation for CSBM (471 and 383 g for the low and high levels), and increased for SBH with increasing levels of supplementation (589 and 644 g for low and high levels).

Digestibility of the NDF (DNDFI divided by NDFI; NDFD) was not affected by supplementation (P=.93) or by level of supplementation (P=.47). Comparison of CSBM and SBH showed a treatment by level interaction (P=.001) with decreasing NDFD for CSBM as level of supplementation increased (54.6% and 51.0% for low and high levels), and increasing NDFD for SBH as level of supplementation increased (58.9% and 63.3 for low and high levels) (Table 3-14).

Comparison of WM with combined data of CSBM and SBH showed lower (P=.0003) NDFD for WM (53.2%) than combined

Table 3-14. Total tract neutral detergent fiber digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) (1992-1993).

		NDF Intake g d^{-1}					
Source	Level	Hay	Suppl	Total	Feces, g d^{-1}	Digestible NDFI, g d^{-1}	NDFD, %
CONTROL	0	861	0	861	378	483	55.8
CSBM	Low	842	24	866	395	471	54.6
WM	Low	806	86	892	407	485	54.6
SBH	Low	825	180	1005	416	589	58.9
CSBM	High	688	57	745	362	383	51.0
WM	High	634	183	817	393	424	51.8
SBH	High	656	364	1020	376	644	63.3
SEM							
CONTROL		27	-	30	15	18	0.8
CONCENTRATES		39	10	42	21	26	1.2
CONTRASTS, (P value)							
Control vs suppl.		.0003	.0001	.38	.42	.31	.93
Low vs high level		.0001	.0001	.08	.09	.14	.47
WM vs CSBM&SBH		.33	.008	.13	.47	.003	.0003
CSBM vs SBH		.53	.0001	.0001	.38	.001	.0001
WM vs CSBM&SBH/level		.87	.46	.75	.52	.35	.11
CSBM vs SBH/level		.84	.0001	.11	.87	.006	.001

data of CSBM and SBH (57%). This better response in NDFD was due to the higher fiber digestibility achieved with increasing levels of SBH supplementation.

Results obtained in the hay intake and digestibility trials with sheep agree with Chase and Hibberd (1987), who found no difference either in hay intake, or digestibility when corn was fed at .23% BW, but decreased hay intake and hay digestibility when corn supplementation was increased. Much of the decrease in hay intake observed with grain feeding was probably due to the observed depression in fiber digestion. In agreement with this statement, Horn and McCollum (1987) concluded that the level at which concentrates affect forage intake is around .3% BW of supplement DM.

A similar decrease in NDFD was reported by Galloway et al. (1991) when ground corn, or whole corn were fed at .67% BW. They suggested that corn could affect fiber digestion with warm and cool season grasses when the level is .5% BW, or when forage quality is low.

Sanson and Clanton (1989) and Goetsch et al., (1991) also found a trend for lower fiber digestion as corn supplementation increased. In both cases the lack of ammonia was suggested as the reason for depression in digestibility of all diets because in their trials levels of ruminal ammonia were below the minimal recommended amount (2 to 5 mg dL^{-1}) for maximal microbial growth (Satter and Slyter, 1974).

Goetsch et al. (1991) suggested that bermudagrass consumption may have affected NDF digestion by influencing residence time of potentially digestible fiber in the gut. They suggested that corn reduces bermudagrass NDF digestion slightly more when NDF content of the forage is lower, and emphasized that corn decreases pH which impairs microbial attachment (more critical for digestion of high quality forages) to fibrous particles.

Klopfenstein and Owen (1988) and Brown and Weigel (1993) reported increased total DMI as level of corn or SBH increased in the diet. Both supplements increased dietary DMD linearly as level of supplement increased in diet, and small differences were recorded between sources at a given level of supplementation. However, fiber digestibility increased with higher levels of SBH, while fiber digestibility decreased as level of corn supplementation increased.

In our study, the higher digestibility of the total diet NDF in SBH supplemented sheep resulted from the high intake of highly digestible NDF from this concentrate. The higher intake of highly digestible NDF was the main mechanism responsible for producing the higher ADG in cattle fed SBH at the high level of supplementation. This statement is also supported by the similar levels of voluntary hay intake observed with all supplements. These data support the contention that SBH did not interfere with the cellulolytic activity of ruminal microorganisms like corn did, an interference that decreased the fiber digestibility of forages used in both years. Additionally, the increased DOMI (Table 3-8), suggests that SBH supplementation should increase energy intake of cattle maintained on low quality forages.

The previous results agree with Grisby et al., (1992) who reported that ruminal and total tract digestibility of DM, OM and NDF increased with increasing amounts of SBH in the diet.

In reference to WM, results obtained from the digestibility trial do not agree with Ovenell et al. (1991) who recorded increased hay and total diet DMD with supplementation of CSBM or WM compared to unsupplemented animals, but no differences between these two supplements. They reported that hay DMI and DMD tended to be greater for WM than for CSBM, possibly because of the 45% lower starch content of WM.

In agreement with this report, Sunvold et al. (1991) found that DMI and DMD were similar when steers were supplemented with .31% of BW of a SBM sorghum grain mixture, or with .39% BW of WM. Neutral detergent fiber digestibility tended to be greater for steers fed WM than for those fed SBM sorghum grain. Cows fed WM and CSBM supplements performed similarly indicating that greater fiber concentration and lower energy concentration of WM than CSBM may offset more favorable effects on forage intake and(or) digestibility. They concluded that WM seem to be used by cows with an efficiency at least equal to that of an isonitrogenous supplement of CSBM. They suggested that increasing levels of WM offered daily increased forage intake, which may have resulted from providing more total protein.

The higher ADG observed with the high level of WM supplementation compared to the high level of CSBM supplementation (.14 kg d^{-1} higher for WM than CSBM) was obtained with better feed efficiency. At the high level of supplementation, feed efficiency was 9.6 for WM and 11.0 for CSBM (Table 3-8).

It is also possible that the higher CP concentration of WM (19.2% vs 12.5% CP for WM and CSBM respectively), produced better conditions for rumen microorganisms. This resulted in higher microbial efficiencies, and higher efficiencies along with faster rates of passage may be responsible for the higher ADG in the high level of WM supplementation. In addition, it is possible that higher arginine concentration in WM, as compared to CSBM and SBH, could promote partitioning of nutrients through mechanisms involving STH which would produce higher ADG with less fat deposition.

Summary and Conclusions

Results of these trials suggest that supplementation improved performance and body condition of cattle consuming bermudagrass hay. Cattle fed CSBM and SBH had greater BCS change than WM at both feeding levels. At the low feeding level, cattle gains were similar for all supplements, but at the high feeding level cattle fed SBH had higher gains than cattle fed CSBM. Higher digestibility of NDF in SBH supplemented animals compared to CSBM and WM was one of the mechanisms contributing to higher weight gains.

CHAPTER IV

EFFECT OF CONCENTRATE SOURCE ON DIGESTION AND RUMEN VARIABLES OF STEERS

Introduction

Supplementation with concentrates containing highly digestible fiber and a lower starch concentration such as SBH and WM had less negative associative effects than CSBM. The previous research (Chapter III) showed that cattle forage intakes and weight gains were similar for all supplements at the low feeding level, but at the high feeding level cattle fed SBH and WM had higher weight gains (.95 and .90 kg d^{-1} for SBH and WM, respectively) than cattle fed CSBM (.76 kg d^{-1}).

Digestibility of NDF was higher for sheep fed SBH than CSBM or WM at both feeding levels in these studies. At the low feeding level, NDFD for SBH was 4 percentage units higher (58.9%) than CSBM (54.6%) and WM (54.6%), and at the high feeding level the NDFD percentage difference was 12 units better for SBH (63.3%) than CSBM (51.0%) and WM (51.8%). The higher total tract NDFD for SBH explains partially the better performance of steers fed this supplement. However, similar hay intake, forage intake change and substitution rate among supplements, suggest that mechanisms other than intake were involved in producing differences in ADG at the high feeding level.

It is possible that SBH at the high feeding level had greater rumen liquid pH and consequently increased rate of forage digestion. In addition, SBH may increased rate of passage of particles of the base forage and rumen liquid turnover rate.

The lower BCS found in WM supplemented cattle may be related to the proportions of VFA's (higher acetate and lower propionate) produced by this concentrate.

This study was designed to measure rumen variables, (eg., pH, ammonia and VFA concentrations) and kinetic parameters, (eg., rate of NDF degradation, and liquid and solid passage rates) in steers fed bermudagrass hay supplemented with concentrates containing different sources of carbohydrates.

Materials and Methods

The study was conducted at the University of Florida Nutrition Laboratory in Gainesville, from June 13 to September 4, 1994, using the same concentrates fed in the 1993 intake and performance trial with cattle, and the corresponding intake and digestibility trial with sheep.

Experimental design. A 4 x 4 Latin Square design was used. Each experimental period consisted of 21 days, with 13 days for adaptation to the experimental diet, and 8 days for sample collection. Initial assignment of animals to treatments, and pens was at random. Sequence of treatments for the Latin Square design appears in Table 4-1:

Table 4-1. Assignment of treatments in Latin Square design.

Period	Pen 1	Pen 2	Pen 3	Pen 4
1	CSBM	WM	SBH	CONTROL
2	WM	CONTROL	CSBM	SBH
3	SBH	CSBM	CONTROL	WM
4	CONTROL	SBH	WM	CSBM

Animals. Six months prior to initiating the experiment four crossbred steers, of approximately 1.5 years of age and an average body weight of 450 kg, were fitted surgically with ruminal, and proximal duodenal cannulae. Steers were dewormed before the beginning of the experiment and allotted to individual pens, with ad libitum access to water, and a mineral mix (25% NaCl, 17 to 20% Ca, 6% P, 1% Fe, .5% Zn, .15% Cu, .1% Mg, .06% F, .02% Mn, .01% Co, and .004% Se; Seminole Feed, Ocala, FL.).

Diets. Bermudagrass hay harvested as first cut in May of 1994 was chopped to approximately 8 cm and fed twice a day (0800 and 1400 h) as base diet. The amount of hay offered was determined by adjusting the quantity fed daily to provide between 650 and 800 g of orts each day. Concentrates offered were: no supplement (CONTROL), corn-soybean meal (CSBM), wheat middlings (WM) and soybean hulls

(SBH). Concentrates were offered once daily between the collection of orts and the feeding of the morning hay. Amount of supplement fed was adjusted twice during the preliminary phase and was targeted to provide the average for both years of the concentrate intake, as percentage of total intake, of the two intake and performance trials with steers. Targeted concentrate intakes were: 34, 37 and 39% of the total intake for CSBM, WM and SBH, respectively (Table A3-4). Daily concentrate intake was fixed during the collection phase.

Feed sampling procedure. Samples of hay, and concentrates were taken daily during the 8 day sample collection period, and composited for analysis of DM, OM, CP, NDF, ADF, lignin and starch.

Site and extent of nutrient digestion. The rate of flow of digesta can be calculated by reference to indigestible markers which are either present in the feed or given independently (Faichney, 1975). External markers were used to estimate different variables. Chromium oxide was used to measure digestibility in the rumen and the total tract; Cobalt-EDTA was the marker for the rumen liquid phase; Dysprosium and Ytterbium were used to estimate rumen solid kinetics of small and large rumen particles, respectively.

Chromium oxide (Cr_2O_3) was used to determine dry matter (DM), organic matter (OM) and neutral detergent fiber (NDF) digestibility in rumen and total tract of steers. Gelatin capsules containing 10 g of Cr_2O_3 were dosed at 0800, and 2000 during days 9 to 17, and at 0800 on day 18 of each period.

Duodenal (150 ml) and fecal grab samples (100 g) were collected three times daily at 8-h intervals starting at 0800 on day 15 through 18 with only a 6-h interval between days. Therefore, 12 individual samples were collected for each site: one sample at each even hour of the 24 h feeding cycle (Hussein et al., 1991). Fecal samples were placed in a plastic pan and dried in a forced air oven at 60 °C. Samples were composited by animal within period and allowed to dry for 48 h.

Duodenal samples were collected by removing the cannula plug and waiting for digesta to flow into plastic bags attached to the duodenal cannula with rubber bands. Collection of samples required up to 15 minutes. Each duodenal sample was placed in a plastic bottle and stored frozen at -20 °C until analyzed. At the end of all four periods, duodenal samples were thawed and 100 ml from each bottle were composited for each animal in each period (12 sample times for each animal in each period were composited to one sample and analyzed).

Two 100 ml aliquots of the composited duodenal samples for each animal-period, were freeze dried, and analyzed for DM, OM, Cr, and NDF. Two 100 g aliquots of the dried composited fecal grab samples for each animal-period were ground through a 2 mm screen using a Wiley mill, and analyzed for DM, OM, Cr, and NDF. Rumen, and total tract digestibilities of DM, OM, and NDF were calculated by the marker ratio technique (Schneider and Flatt, 1975).

Rumen liquid passage and pH determination. Rumen liquid turnover was determined using Cobalt-EDTA (Co-EDTA; Udén et al., 1980). The Co-EDTA solution (250 ml distilled water containing 6180 ppm of Co for periods 1 and 2, and 4080 ppm of Co for periods 3 and 4), was placed under the ruminal mat on day 14 after feeding the concentrate (0800 h), using a 2.5 cm internal diameter rubber tubing.

Starting on day 14, rumen fluid samples (250 ml approximately) were collected from the anterior, middle, and posterior regions of the rumen at: 2, 4, 6, 8, 12, 18, 24, and 36 hours after Co-EDTA solution had been placed into the rumen. Rumen fluid samples were strained through four layers of cheesecloth into plastic collection bottles. Rumen fluid pH was measured with a portable pH meter (Corning M90, Corning, Inc. New York, 14831) immediately after collection in bottles and before samples were acidified (5 ml of 20% H_2SO_4 per 100 ml of fluid; Streeter et al., 1990), and frozen at -20 °C until analysis.

Prior to analysis, rumen fluid samples were thawed, centrifuged (10,000 x g, 15 min.), and cobalt concentration was determined by atomic absorption spectrophotometry using acetylene as the oxidant (Model 5000 series X03, Perkin-Elmer, Norwalk, CT). Liquid turnover was estimated by regressing the natural log of rumen cobalt concentration against time (Grovum and Williams, 1973; Colucci et al., 1990). Rumen liquid passage rate (% h^{-1}) was the absolute value of the slope. Rumen fluid volume (L) was estimated by dividing the amount of cobalt dosed by the antilog of the intercept at zero time (Colucci et al., 1990). Flow of liquid (L d^{-1}) from rumen was calculated as the multiple of volume, rate of passage and day (24 h) (Colucci et al., 1990).

Volatile fatty acids and ammonia determination. Rumen fluid samples used for cobalt analyses also were utilized for VFA and ammonia analyses. Volatile fatty acids were analyzed by gas chromatography (Supelco, Inc. 1975), and after rumen fluid was filtered through .45 μm microcel filters, ammonia was analyzed using a colorimetric analysis (Technicon, 1978).

Rumen solid passage. Kinetics of rumen large and small particles were determined using Ytterbium (Yb) and Dysprosium (Dy) labelled particles, respectively. Large and small particles were obtained prior to initiating the trial from the steers and a Holstein fistulated cow consuming bermudagrass hay without supplementation by wet sieving reticulo-rumen contents collected from the raft rumination pool. The fraction retained on a 4 mm screen was considered large particles, and the fraction which passed through the 1.18 mm screen was considered the small particles.

Dy and Yb solutions were prepared by dissolving 2.5 g of $DyCl_3.6H_2O$, or $YbCl_3.6H_2O$ per liter of distilled water. Small and large particles were immersed in their respective marker for 24 h. After soaking, excess fluid was poured off through a 0.5 mm screen to recover large particles, and through a 0.075 mm screen to recover small particles. Six successive washes (one per hour), were done by resuspending large and small particles in distilled water and repeating the screening procedure. Labeled large and small particles were dried in a forced air oven at 60 °C for 48 h and stored until placing in the rumen (Goetsch and Galyean, 1983).

On day 15 prior to the morning feeding, labeled large and small particles were administered through the rumen cannulae: 125 g of Yb-labeled (DM basis) large particles, and 400 g of Dy-labeled (DM basis) small particles. The amount of marker dosed was calculated according to the formula (Ellis et al., 1980):

Dose (μg/100 kg BW)= MAL x F/100 kg BW x $1/k_2^{-day}$ x D x (1/.5)

where:

MAL = minimal analytical level for the marker, μg/g DM
F = DM fill for segment of interest, g/100 kg BW
k_2 = approximate turnover expected for the marker, in days
D = days post dose of last collection.

On day 15, 16, and 17, samples of 250 ml of duodenal contents were collected through the duodenal cannulae at: 4, 8, 12, 16, 20, 24, 28, 32, 36, 42, 48, 54, 60, and 72 h postdosing. Duodenal contents were placed in plastic bottles, and frozen at -20 °C until analyzed.

Labeled large and small particles, and duodenal samples were analyzed for DM, and for Yb and Dy concentration (Firkins et al., 1984; Karimi et al., 1987) by atomic absorption spectrophotometry (Perkin-Elmer 5000 series X03, Perkin-Elmer Norwalk, CT) using nitrous oxide as the oxidant.

Excretion curves for Dy and Yb were fit to the series of two compartment models (emerging) with either no age dependency (G1G1) or with increasing orders of gamma age dependency in the fast compartment (GnG1, n= 2 to 4) using the nonlinear procedure of SAS (1987; PROC NLIN, iterative Marquardt method) described by Pond et al. (1988) and published by Moore et al. (1992). Selection of the best fitting model for each marker was made after testing all the nonlinear models on data obtained for each animal-period, i.e., G1G1 and GnG1 (n= 2 to 4) models were tested in each animal-period.

Criteria for selecting the model that best fit the data for all animals in all treatments, considered the closest values among asymptotic confidence interval, lowest residual errors and the most observations hidden in graphs of predicted vs actual data points (Moore et al., 1992). For both, small and large particles, the best fitting model selected to evaluate digesta kinetic estimates in rumen was G4G1.

These models estimate passage from two compartments, fast and slow, and also estimate a time delay. Passage rate from the slow compartment may represent the raft rumination pool, where comminution and further degradation of particles take place, whereas the passage rate from the fast compartment may represent the turnover or rumen transport pool (Ellis, 1994; Hungate, 1966).

After models were selected, secondary variables were calculated and statistically analyzed in the a Latin Square design. Mean retention time in the fast compartment (FMRT) was calculated as n/lambda, where n is the level of age dependency and lambda is calculated by the non-linear model and describes the passage kinetics for the fast compartment. Mean retention time for the slow compartment (SMRT) was calculated as $1/k_s$, where k_s represents the rate of passage for the slow compartment and is also estimated by the non-linear model. Total mean retention time in rumen (TRMRT) was calculated as FMRT + SMRT + time delay. The latter is also estimated by the non-linear model and represents the time needed for particle passage to the duodenum (Moore et al., 1992).

Duodenal DM output was calculated as (mg of marker dosed/Czero) x k_s x 24 hours, where Czero represents initial marker concentration in the slow compartment and is estimated by the non-linear model (Moore et al., 1992).

Fill (% BW) of undigested DM in the rumen was the sum of fills from the two compartments. For the slow compartment the ratio Dose/Czero was used, and for the fast compartment the equation (Dose x k_s) / (lambda x constant x Czero) was applied to estimate fill. Dose was the amount of marker used and the constant is a function of age dependency which estimates equivalent initial concentration of marker in the age dependent compartment, for all age dependent and age independent models. Passage rate from the age dependent compartment was calculated as lambda x constant and that from the age independent compartment was equal to k_s (Luginbuhl et al., 1995).

Lag time, and rate and extent of disappearance. The nylon bag technique was used to determine lag time, and rate and extent of disappearance of hay and concentrates in the rumen. Each concentrate was evaluated when each steer was fed the respective supplement. For example, SBH and hay were evaluated when steers consumed SBH.

Samples of hay and concentrates were ground through a 2 mm screen, and air equilibrated at room temperature prior to being weighed into the bags. Nylon bags of 10 x 21 cm with an average pore size of 30 x 70 μm were used. The open side of bags was closed using a rubber stopper (# 8) which was secured with two rubber bands (# 18). Five grams of forage (as fed basis), or five grams of concentrate (as fed basis), were weighed and put into one bag. Bags of hay, or concentrate were placed inside a polyester bag (38 cm x 45 cm) that was attached to the rumen cannulae through a plastic string.

The nylon bags with concentrate were placed in the rumen before the bags with hay. Starting on day 15 at 2000 h, concentrate bags were placed in the rumen in reverse order of the following incubation times: 0, .5, 1, 2, 4, 6, 8, 12, 18, 24, and 36 hours. All bags containing concentrate were removed at the same time (day 17 at 0800 h), and rinsed under tap water until the water squeezed from bags appeared clear. Bags then were dried overnight in a forced air oven at 55 °C, and the entire concentrate remaining inside the bag was analyzed for DM (100 °C) and NDF.

On Day 17 at 1200 h, bags with hay were placed in the rumen in reverse order of the following incubation times: 0, 2, 4, 6, 8, 12, 18, 24, 48, 72, and 96 hours. Nylon bags with hay were removed on Day 21 at 1200, washed, dried and analyzed in the same way as concentrate bags. The model kinetics used to evaluate DM and fiber digestion of both concentrates and hay was described by Mertens and Loften (1980):

$$Y = D_0 * e^{-k(t - L)} + U \quad \text{when } t>L\text{, and}$$

$$Y = D_0 + U \quad \text{when } 0<t<L$$

Where: Y = DM or NDF residue at time after incubation t,
D_0 = slowly digestible fraction at time $t<L$,
$D_0 = Y - U$,
k = digestion rate constant,
L = discrete lag time,
U = undigested fraction (24 h for concentrates or 72 h for hay), and
t = time after incubation

Rate of DM or NDF digestion and lag time of the slowly or potentially digestible fraction were calculated using the non-linear iterative procedure of Marquardt in SAS (1987). Parameter estimates for each individual sample were used to estimate residuals for that sample instead of a single set of parameter estimates across all samples within each treatment (Mertens and Loften, 1980). Calculation of individual parameter estimates was as follows:

A or Soluble fraction = DM or NDF weight of sample at time zero - DM or NDF weight of sample at time zero after rinsing with tap water.

B or Potentially digestible fraction = Soluble fraction - undigested fraction.

C or Undigested fraction = DM or NDF weight of sample after incubation (36 h for concentrates or 96 h for hay).

Statistical analysis. Data were analyzed by analysis of variance using the general linear model (GLM) of the Statistical Analysis System (SAS, 1987). The mathematical model for analysis of estimates obtained from rate of passage models, from rate of degradation model, and digestibility using chromium was:

$$Y = \mu + A_i + P_j + T_k + E_{ijkl}$$

Where: Y = Variable.
μ = General mean.
A_i= Animals.
P_j= Periods.
T_k= Treatments: control, and high levels of CSBM, WM or SBH.
E_{ijkl}= residual error.

The mathematical model used for analysis of multiple measurements within each animal-period, as was the case for rumen fluid pH, VFA and rumen ammonia concentrations, considered such measurements nested within treatments and were tested using the subsampling error as error term (Damon and Harvey, 1987; Gill, 1978):

$$Y = \mu + A_i + P_j + T_k + S_{kl} + E_{ijklm}$$

Where: Y = Variable.
μ = General mean.
A_i= Animals.
P_j= Periods.
T_k= Treatments: control, and high levels of CSBM, WM or SBH.
S_{kl} = Sampling times nested within treatments-periods.
E_{ijklm} = residual error.

Analysis of the responses over time for ammonia, pH and VFA was made using the repeated measures analysis of variance (Littel, 1989). The polynomial option was used in the repeated statement of SAS to compare slopes. Linear, quadratic and cubic responses were tested (Freund et al., 1986; Littel, 1989).

Main treatment effects were considered to exist when P-value of parameter was less than .11 and a tendency was indicated by P-values ranging from .11 to .15. Due to different number of observations least square means with PDIFF option of GLM (SAS, 1987) were used to determine the probability level of the difference between treatments.

Results and Discussion

In Period 3, one of the steers became sick (rumen atony) and had to be removed from the trial. For the next period, this animal was included again in his respective treatment and all samples were collected. However, results from this animal for the last period were not included in the final analysis because this steer consumed less forage (40% below first period) and less concentrate (50% below first period) (Table A4-1).

In addition, this steer showed erratic responses in ruminal parameters. As an example, mean retention time of large particles in rumen was 52% greater (88 vs 47 h) than the average of the other three steers fed the same concentrate (SBH), this delay in passage was accompanied with a 50% decrease in the rate of particle passage. Exclusion of this steer from the Latin Square for Periods 3 and 4 left four observations for control and WM treatments, and three observations for CSBM and SBH.

Chemical composition of bermudagrass hay offered to steers was comparable to that in experiments of voluntary intake and performance with steers and digestibility with sheep, except for one important characteristic. The main difference was the low crude protein concentration (5.7%), which was unexpected and difficult to explain because paddocks used to harvest and prepare hay were the same as in previous experiments, and similar management was followed including fertilization levels, maturity and date of cutting. Crude protein concentration of WM was the highest among concentrates (Table 4-2).

Table 4-2. Chemical composition of bermudagrass hay and concentrates fed to steers.

Item	Bermudagrass hay	CSBM	WM	SBH
Dry matter, %	89.1	88.9	86.9	89.1
		% DM basis		
Organic matter	95.2	93.3	91.8	94.8
Crude protein	5.7	12.5	18.6	12.4
Neutral detergent fiber	79.3	15.2	38.8	59.4
Acid detergent fiber	42.6	6.0	13.8	50.1
Lignin	5.9	1.1	3.7	1.6
Starch	5.5	63.2	26.4	4.5

The TDN:CP ratio of bermudagrass hay was 9.3 indicating that there was not enough protein in the hay to match its available energy. The TDN value was estimated by the product of hay OM (95.2%) and total OM digestibility (Moore, 1987). Total OMD of hay (55.5%) was obtained from the chromium oxide concentration in fecal samples collected during this trial.

Intake. Hay intake was not different for supplemented steers compared to unsupplemented steers (Table 4-3). Concentrate intake represented 0.87, 0.96 and 0.94% of body weight for corn-soybean meal, wheat middlings and soybean hulls, respectively. Total intake (hay intake + concentrate intake) was higher (P=.01) for supplemented than unsupplemented steers. Forage intake change and substitution rate were as in Chapter III not different among concentrate sources (Table 4-3).

In this experiment, hay intake for CSBM was different than that obtained in Chapter III, where hay intake was reduced for all concentrate sources at the high level of supplementation. In addition, hay intake (% BW) for unsupplemented steers was 26.5 and 12.2% lower than the hay intake of unsupplemented steers in the performance trials (2.15, 1.80 and 1.58% for years 1, 2 and this trial, respectively). Total intake responded as in Chapter III with higher values for supplemented steers. Forage intake change and substitution rate were, as in Chapter III, not affected by sources of supplementation.

Digestibility in the rumen and total tract using chromium. Supplementation of concentrates increased dry and

Table 4-3. Least square means for dry matter intake (% BW) by steers fed different concentrate sources.

	Intake				
Treatment	Hay	Concentrate	Total	FIC[c]	SR[d]
CONTROL	1.58 ± .04	0.00	1.58^{a} ± .04	---	---
CSBM	1.58 ± .05	0.87 ± .02	2.45^{b} ± .04	.03 ± .07	.03 ± .09
WM	1.48 ± .04	0.96 ± .01	2.44^{b} ± .05	-.09 ± .06	-.10 ± .07
SBH	1.51 ± .05	0.94 ± .02	2.45^{b} ± .04	-.06 ± .07	-.07 ± .09

[ab] Values with different superscript in each column differ ($P<.01$)

[c] FIC: forage intake change = forage intake with supplement - forage intake when fed alone.

[d] SR: substitution rate = decrease in forage intake per unit of supplement fed.

organic matter flow to duodenum and feces, and dry and organic matter digestibility in rumen and total tract (Tables 4-4 and 4-5). Among concentrates, WM had higher total DM, and total OM intakes, and higher DM flow to duodenum and feces than CSBM and SBH. Digestion of OM in rumen was higher (52.1%) for SBH than all other treatments. Total tract OM digestion had the same response trend as in the digestibility trial with sheep, the lowest OM digestion (55.5%) was for unsupplemented steers, similar values were estimated for CSBM (63.8%) and SBH (63.7%), and intermediate (60.0%) OM digestion was calculated for WM supplemented steers (Table 4-5).

Calculated values for NDF digestion in total tract were 5.7% lower than values obtained for NDF digestion in rumen (Table 4-6). The same trend has been reported by other researchers but no explanation was given for this unlikely result (Galloway et al., 1993a; Galloway et al., 1993b; Chan et al., 1991).

One possible explanation may be related to percentage of recovery for chromium oxide, which has been reported to be incompletely recovered (94.2%) in feces (Schneider and Flatt, 1975). In addition, Prigge et al. (1981) indicated that chromium oxide does not associate with the particulate phase of the digesta and variations in chromium oxide excretion are due mainly to its incomplete mixing with the digesta in the gastrointestinal tract.

Table 4-4. Rumen and total tract dry matter digestibility using chromium oxide (Cr_2O_3).

	Treatments			
	CONTROL	CSBM	WM	SBH
Dry matter				
Intake, kg d^{-1}				
Hay	6.53 ± .24	6.16 ± .32	6.11 ± .24	5.94 ± .32
Supplement	0.00	3.37 ± .24	3.90 ± .18	3.59 ± .24
Total	6.53^a ± .07	9.53^b ± .09	10.01^c ± .07	9.53^b ± .09
Flow, kg d^{-1}				
Duodenum	3.53^a ± .08	4.64^{bc} ± .10	5.00^c ± .08	4.30^b ± .10
Feces	2.77^a ± .05	3.25^b ± .07	3.75^c ± .05	3.28^b ± .07
Digestion, %				
Rumen	45.4^a ± 0.9	50.8^b ± 1.2	50.0^b ± 0.9	54.5^c ± 1.2
Total	57.8^a ± 0.3	65.8^b ± 0.5	62.6^c ± 0.3	65.5^b ± 0.5

[abc] Values with different superscript in each row differ (P<.01).

Table 4-5. Rumen and total tract organic matter digestibility using chromium oxide (Cr_2O_3).

	Treatments			
	CONTROL	CSBM	WM	SBH
Organic matter				
Intake, kg d^{-1}				
Hay	6.19 ± .23	5.85 ± .31	5.80 ± .23	5.65 ± .31
Supplement	0.00	3.16 ± .22	3.57 ± .17	3.41 ± .22
Total	6.19^a ± .07	9.01^b ± .09	9.38^c ± .07	9.06^b ± .09
Flow, kg d^{-1}				
Duodenum	2.82^a ± .06	3.78^b ± .09	4.07^c ± .06	3.45^b ± .09
Feces	2.57^a ± .05	2.98^b ± .07	3.43^c ± .05	3.00^b ± .07
Digestion, %				
Rumen	42.5^a ± 1.0	47.9^b ± 1.3	46.7^b ± 1.0	52.1^c ± 1.3
Total	55.5^a ± 0.4	63.8^b ± 0.5	60.0^c ± 0.4	63.7^b ± 0.5

[abc] Values with different superscript in each row differ ($P<.01$).

Table 4-6. Rumen and total tract NDF digestibility using chromium oxide (Cr_2O_3).

	Treatments			
	CONTROL	CSBM	WM	SBH
NDF				
Intake, kg d^{-1}				
Hay	5.19 ± .20	4.91 ± .26	4.87 ± .20	4.74 ± .26
Supplement	0.00	0.53 ± .13	1.53 ± .10	2.22 ± .13
Total	5.19^a ± .11	5.44^a ± .14	6.41^b ± .11	6.96^c ± .14
Flow, kg d^{-1}				
Duodenum	1.72^a ± .08	1.97^a ± .11	2.23^b ± .08	1.98^a ± .11
Feces	2.09^a ± .05	2.33^b ± .07	2.76^c ± .05	2.37^b ± .07
Digestion, %				
Rumen	67.1^a ± .9	74.0^b ± 1.2	72.2^b ± .9	73.9^b ± 1.2
Total	60.4^a ± .5	69.5^b ± .7	65.7^c ± .5	68.9^b ± .7

[abc] Values with different superscript in each row differ ($P<.01$).

Supplementation increased total NDF intake (Table 4-6). Soybean hull supplemented steers consumed 8, 22 and 25% more NDF than WM, CSBM and unsupplemented steers, respectively. However, rumen and total tract digestibility of NDF for this concentrate was similar to other supplements and 7 percentage units better than unsupplemented steers (Table 4-6).

Results in our study do not agree with Galloway et al. (1993a) who reported similar OM digestion in rumen between control steers and steers fed with .67% BW of ground corn or .67% BW of whole corn and consuming bermudagrass hay. Digestion of OM in total tract increased by 4 percentage units when .67% BW ground corn was fed. They also reported decreased NDF digestion in rumen and total tract when corn was supplemented (56.4%, 54.2% and 54.8% for control, ground and whole corn in rumen, and 56.7%, 53.5% and 50.5% for control, ground and whole corn in total tract).

Stokes et al. (1988) reported increased total tract OM digestion by steers supplemented with 1% BW ground corn and fed a fescue hay based diet. However, total tract NDF digestion decreased by 4 percentage units (63.1% vs 67.2%) in corn supplemented steers.

Galloway et al. (1993b) supplemented .28% BW ground corn or .39% BW SBH to steers consuming bermudagrass hay. They reported similar OM digestion in the rumen for control and corn supplemented animals (57.4%) but increased OM digestion in rumen of steers fed SBH (67.9%). Total tract OM digestion was lower for unsupplemented steers (62.5%), but higher for corn and SBH supplemented cattle with no difference among concentrates (68.2%). Rumen NDF digestion was also increased by supplementation (59.8%, 64.3% and 70.7% for control, corn and SBH), but total tract NDF digestion was similar among treatments (65.5%, 64.9% and 69.4% for control, corn and SBH).

Brake et al. (1989) supplemented .60% BW ground corn to beef cows consuming bermudagrass hay. They reported similar OM digestion in rumen (54.6% vs 53.5% for control and ground corn, respectively), but increased total tract OM digestion in corn supplemented (65.5%) cows compared to control (52.4%) cows. Total tract NDF digestion was increased by 5 percentage units due to ground corn supplementation (55.5% vs 60.6% for control and corn, respectively).

Increased OM and NDF digestion in rumen and total tract was reported by Chan et al. (1991), when .61% or 1.22% BW of corn or SBH was supplemented to beef cows consuming a low quality hay. Organic matter digestion in rumen was 41.0%, 49.3%, 51.3%, 53.4% and 53.6% for control, low and high corn, and low and high SBH supplementation, respectively. Organic matter digestion in total tract was 46.7%, 58.1% 61.2%, 66.3 and 66.2 for control, low and high corn, and low and high SBH supplementation. Digestion of NDF in rumen was increased only by SBH: 60.5%, 61.7%, 60.7%, 67.4 and 68.2%

for control, low and high corn, and low and high SBH supplementation. Values reported for total tract NDF digestion were slightly lower than values for rumen NDF digestion: 59.6%, 60.4%, 59.8%, 66.3% and 66.2% for control, low and high corn, and low and high SBH supplementation, respectively.

Lag time, and rate and extent of disappearance of potentially digestible DM and NDF from nylon bags. The statistical analysis of concentrates was performed as a complete randomized design because less number of treatments (CSBM, WM and SBH) and missing values (CSBM and SBH in animal number 2). The DM soluble fraction of SBH was lower (P=.01) than the DM soluble fractions of CSBM and WM (41.8, 37.7 and 23.8% for CSBM, WM and SBH, respectively; Table 4-7). However, the DM potentially digestible fraction of SBH was higher (P=.01) than CSBM and WM, and the DM potentially digestible fraction of CSBM was higher than the WM fraction (51.3, 42.6 and 63.3% for CSBM, WM and SBH, respectively; Table 4-7).

There were no differences among concentrates on DM lag time of the potentially digestible fraction of concentrates (Table 4-7). The lag phase of digestion is defined as the period of initial fermentation when digestion either does not occur or occurs at a greatly reduced rate (Mertens, 1977). The lag phase is a time needed for wetting of feed,

Table 4-7. Least square means for digestion kinetics of DM in concentrates using nylon bags.

	Treatment		
	CSBM	WM	SBH
Soluble fraction, %	$41.8^{a} \pm 1.8$	$37.7^{a} \pm 1.5$	$23.8^{b} \pm 1.8$
Potentially digestible fraction, %	$51.3^{a} \pm 1.7$	$42.6^{b} \pm 1.5$	$63.6^{c} \pm 1.7$
Undigestible fraction, %	$6.9^{a} \pm 1.2$	$19.7^{b} \pm 1.0$	$12.6^{c} \pm 1.2$
Kinetics of potentially digestible fraction			
Lag time, h^{-1}	0.9 ± 0.8	0.1 ± 0.5	1.9 ± 0.8
Rate of digestion, % h^{-1}	$5.1^{a} \pm 0.9$	$12.6^{b} \pm 0.7$	$4.5^{a} \pm 0.9$
Extent of digestion, 24 h	$66.6^{c} \pm 4.0$	$63.6^{c} \pm 3.5$	$54.9^{d} \pm 4.0$

[ab] Values with different superscript in each row differ ($P<.01$).
[cd] Values with different superscript in each row differ ($P<.05$).

microbial attachment and reproduction, and the initiation of fermentation of the feed (Hungate, 1966).

Wheat middlings showed a greater ($P=.01$) rate of digestion of potentially digestible DM than CSBM and SBH (5.1, 12.6 and 4.5% for CSBM, WM and SBH, respectively; Table 4-7). Extent of DM digestion estimated from the nylon bag technique for CSBM and WM was greater ($P=.05$) than SBH (66.6, 63.6 and 54.9% for CSBM, WM and SBH, respectively; Table 4-7).

The NDF potentially digestible fraction of SBH was higher ($P=.01$) than CSBM and WM (59.5, 40.0 and 68.9% for CSBM, WM and SBH, respectively; Table 4-8). Lag time and extent of digestion of the NDF potentially digestible fraction were similar among concentrates. Digestion kinetics for the potentially digestible NDF in concentrates showed higher ($P=.01$) rate of digestion for WM than CSBM and SBH (Table 4-8).

Compared to unsupplemented steers, concentrates did not affect lag time, rate of digestion or extent of digestion of the potentially digestible fractions of DM and NDF in hay (Tables 4-9 and 4-10).

Results in our study do not agree with Varga and Hoover (1983), who reported similar rates of NDF digestion for WM and corn when dairy cattle were fed a perennial ryegrass hay diet plus a 50:50 mixture of corn and oat. However, extent of NDF digestion at 24 h for these feedstuffs was lower

Table 4-8. Least square means for digestion kinetics of NDF in concentrates using nylon bags.

	Treatment		
	CSBM	WM	SBH
Soluble fraction, %	16.4 ± 4.5	21.4 ± 3.9	16.8 ± 4.5
Potentially digestible fraction, %	59.5^b ± 4.9	40.0^a ± 4.2	68.9^b ± 4.9
Undigestible fraction, %	24.1^a ± 1.8	38.6^b ± 1.5	14.3^c ± 1.8
Kinetics of potentially digestible fraction			
Lag time, h^{-1}	0.7 ± .6	0.9 ± .5	1.1 ± .6
Rate of digestion, % h^{-1}	3.3^a ± .7	10.5^b ± .6	3.8^a ± .7
Extent of digestion, 24 h	38.7 ± 4.2	44.0 ± 3.7	47.5 ± 4.2

[abc] Values with different superscript in each row differ ($P<.01$).

Table 4-9. Least square means for digestion kinetics of DM in hay using nylon bags.

	Treatment			
	CONTROL	CSBM	WM	SBH
Soluble fraction, %	21.4 ± 1.5	21.6 ± 1.7	21.5 ± 1.5	22.1 ± 1.7
Potentially digestible fraction, %	39.6 ± 1.4	39.7 ± 1.6	40.3 ± 1.4	41.7 ± 1.6
Undigestible fraction, %	39.0 ± 1.8	38.7 ± 2.1	38.2 ± 1.8	36.2 ± 2.1
Kinetics of potentially digestible fraction				
Lag, h^{-1}	5.1 ± 1.1	3.7 ± 1.3	4.0 ± 1.1	3.6 ± 1.3
Rate of digestion[a], % h^{-1}	3.9 ± .4	4.8 ± .5	4.3 ± .4	4.4 ± .5
Extent of digestion, 72 h	47.9 ± 2.0	48.0 ± 2.4	47.9 ± 2.0	50.3 ± 2.4

Table 4-10. Least square means for digestion kinetics of NDF in hay using nylon bags.

	Treatment			
	CONTROL	CSBM	WM	SBH
Soluble fraction, %	19.1 ± 1.8	19.6 ± 2.1	20.2 ± 1.8	20.9 ± 2.1
Potentially digestible fraction, %	42.6 ± 1.3	43.1 ± 1.5	42.0 ± 1.3	44.7 ± 1.5
Undigestible fraction, %	38.3 ± 1.9	37.3 ± 2.2	37.8 ± 1.9	34.3 ± 2.2
Kinetics of potentially digestible fraction				
Lag, h^{-1}	4.8 ± 1.2	2.6 ± 1.4	3.6 ± 1.2	3.2 ± 1.4
Rate of digestion, % h^{-1}	3.9 ± .4	4.7 ± .5	4.4 ± .4	4.4 ± .5
Extent of digestion, 72 h	49.8 ± 2.0	50.6 ± 2.3	49.2 ± 2.0	52.2 ± 2.3

(52.1% for WM and 42.3% for corn). For SBH they reported a lower degradation rate (.011 h^{-1}) and lower extent of NDF digestion at 24 h (38.4%).

Mertens and Loften (1980) reported a lag time of 3.05 h, digestion rate of .072 h^{-1} and 65.9 % extent of digestion for Coastal bermudagrass containing 16.3% CP and 67.7% NDF.

Frederickson et al. (1993) reported a higher extent of organic matter digestion by steers consuming prairie hay supplemented with .44% BW of corn. Extent of organic matter digestion of hay at 72 h was 58.8% and 52.2% for corn supplemented and unsupplemented cattle, respectively.

Rumen liquid rate of passage. Supplementation with WM and SBH increased rumen liquid rate of passage (turnover) compared to unsupplemented steers (Table 4-11). Rumen fluid volume was higher for CSBM than SBH supplemented steers. As a result of higher rumen liquid volume for CSBM, flow of liquid from rumen was also higher for CSBM than all other treatments (Table 4-11).

Table 4-11. Rumen liquid kinetics using cobalt.

Treatment	Liquid rate of passage, % h^{-1}	Volume, L	Flow, L d^{-1}
CONTROL	$7.96^{a} \pm .4$	$35.3^{ab} \pm 2.6$	$67.1^{a} \pm 4.2$
CSBM	$8.98^{ab} \pm .6$	$39.2^{a} \pm 3.4$	$86.3^{b} \pm 5.6$
WM	$9.54^{b} \pm .4$	$31.7^{ab} \pm 2.6$	$71.8^{a} \pm 4.2$
SBH	$9.64^{b} \pm .6$	$29.3^{b} \pm 3.4$	$68.9^{a} \pm 5.6$

[ab] Values with different superscript in each column differ ($P<.05$)

Increased rumen liquid rate of passage found in supplemented steers could be related to the small particle size of concentrates. The small feed particle size has been suggested to increase saliva flow and fluid turnover (Owens and Isaacson, 1979). The increased rumen liquid turnover in cattle supplemented with concentrates has been shown to enhance ruminal outflow of soluble feed components, nutrients solubilized by microbial degradation, small particulate feed components (Teeter and Owens, 1983), and ruminal microbial protein flow to duodenum (Owens and Isaacson, 1979).

Related to CSBM our results agree with Pordomingo et al. (1991), who reported no differences in fluid dilution rate when increasing (0, .2, .4, and .6% BW) levels of whole shelled corn were supplemented to steers grazing native grass. Values for rumen liquid rate of passage were 9.7, 11.2, 9.4 and 9.6 % h^{-1} for 0, .2, .4 and .6% BW of whole shelled corn, respectively.

Similar values for rumen fluid dilution rates, 6.8 and 8.5% h^{-1}, were reported by Jones at al. (1988) when 0% or .3% BW of ground corn was supplemented to beef cows consuming bermudagrass hay. Rumen fluid volume was also similar (63.5 and 64.7 L) between control and supplemented cows.

Martin and Hibberd (1990) supplemented 0, .22, .44 or .66% BW of SBH to beef cows consuming a low quality native grass hay. They reported similar rumen fluid dilution rates between all treatments (8.05, 9.15, 8.4 and 9.50% h^{-1} for 0, .22, .44 and .66% BW of SBH, respectively).

Sunvold et al. (1990) reported similar rumen fluid dilution rates when 0, .39 or .77% BW of WM were supplemented to steers consuming dormant bluestem hay. Values reported were 5.8, 7.0 and 8.2% h^{-1} for 0, .39 or .77% BW of WM, respectively. Rumen fluid volume was increased (P=.06) by WM supplementation (40.2, 45.9 and 49.1 L for 0, .39 or .77% BW of WM, respectively). In addition, they reported that rumen fluid flow to the duodenum was not affected by WM supplementation (55.9, 71.52 and 91.68 L d^{-1} for 0, .39 or .77% BW of WM, respectively).

Ruminal solid passage. Compared to unsupplemented steers, soybean hull supplemented steers had a lower (P=.05) mean retention time of small particles of hay in the slow compartment (Table 4-12). In addition, all three concentrate sources reduced the total mean retention time of small particles in the rumen, compared to unsupplemented steers.

All three concentrate sources increased DM output (DMO) of small particles from the rumen. Compared to unsupplemented steers DMO was 21.3, 29.7 and 24.7% higher for CSBM, WM and SBH supplemented steers (Table 4-12). The increase in DMO reflected the higher total DMI of supplemented steers. Total DMI (% BW) for supplemented

Table 4-12. Digesta kinetics for small particles using Dysprosium.

	Treatment			
	CONTROL	CSBM	WM	SBH
Mean retention time, h				
Fast compartment	11.8 ± 1.4	9.8 ± 1.9	10.2 ± 1.4	12.8 ± 1.9
Slow compartment	29.3^{a} ± 2.4	24.0^{ab} ± 3.2	23.2^{ab} ± 2.4	19.4^{b} ± 3.2
Time delay	7.6 ± 1.1	4.6 ± 1.5	4.2 ± 1.1	3.4 ± 1.5
Total	48.7^{a} ± 2.6	38.3^{b} ± 3.4	37.6^{b} ± 2.6	35.6^{b} ± 3.4
DMO from rumen, % BW	.485^{c} ± .04	.616^{d} ± .05	.690^{d} ± .04	.644^{d} ± .05
Fill of undigested DM, % BW				
Fast compartment	.14 ± .03	.15 ± .04	.18 ± .03	.21 ± .04
Slow compartment	.58de ± .04	.62de ± .05	.67^{d} ± .04	.48^{e} ± .05
Total	.72^{c} ± .03	.77^{cd} ± .04	.85de ± .03	.69^{c} ± .04
Rate of passage, % h^{-1}				
Fast compartment	18.5 ± 3.1	16.3 ± 4.1	18.9 ± 3.1	11.0 ± 4.1
Slow compartment	3.6^{a} ± .5	4.2^{ab} ± .7	4.5^{ab} ± .5	5.8^{b} ± .7

[ab] Values with different superscript in each row differ ($P<.05$).
[cd] Values with different superscript in each row differ ($P<.01$).

steers was 35.5% higher (1.58 vs 2.45% BW) than unsupplemented steers (Table 4-3).

Soybean hull supplemented steers had lower (P=.05) fill (% BW) of undigested DM of small particles in the slow compartment compared to WM supplemented steers (Table 4-12). Total fill (% BW) of undigested DM for small particles was higher (P=.05) for WM supplemented steers than unsupplemented and SBH supplemented steers. Rate of passage (% h^{-1}) of small particles from the slow compartment was faster (P=.07) for SBH supplemented steers than unsupplemented steers (Table 4-12).

Compared to unsupplemented steers, supplementation reduced (P=.01) by 38.5% mean retention time of large particles in the slow compartment (Table 4-13). As a consequence of this reduction, supplementation reduced by 20% total mean retention time of large particles of hay in the rumen compared to unsupplemented steers (Table 4-13). Dry matter output of large particles of hay from the rumen was also increased (P=.01) by all three concentrate sources.

Total fill (% BW) of undigested DM for large particles was lower (P=.01) in SBH supplemented steers than CSBM and WM supplemented steers, but similar than control (Table 4-13). The lower total fill and lower fill in the slow compartment in SBH supplemented steers was accompanied by a faster (P=.01) rate of passage for large particles in the

Table 4-13. Digesta kinetics for large particles using Ytterbium.

	Treatment			
	CONTROL	CSBM	WM	SBH
Mean retention time, h				
Fast compartment	17.8 ± 1.3	18.7 ± 1.7	16.9 ± 1.3	18.7 ± 1.7
Slow compartment	44.1^{a} ± 4.0	28.7^{b} ± 5.3	29.5^{b} ± 4.0	23.1^{b} ± 5.3
Time delay	6.9^{a} ± 0.6	3.7^{b} ± 0.8	3.9^{b} ± 0.6	3.3^{b} ± 0.8
Total	68.8^{a} ± 3.3	51.1^{b} ± 4.3	50.3^{b} ± 3.3	45.1^{b} ± 4.3
DMO[c] from rumen, % BW	$.493^{a}$ ± .07	$.729^{b}$ ± .09	$.754^{b}$ ± .07	$.739^{b}$ ± .09
Fill of undigested DM, % BW				
Fast compartment	.22 ± .04	.34 ± .05	.32 ± .04	.34 ± .05
Slow compartment	$.88^{a}$ ± .02	$.93^{a}$ ± .03	$.93^{a}$ ± .02	$.72^{b}$ ± .03
Total	1.10^{a} ± .03	1.27^{b} ± .05	1.25^{b} ± .03	1.06^{a} ± .05
Rate of passage, % h^{-1}				
Fast compartment	11.0 ± .9	8.5 ± 1.2	10.5 ± .9	8.2 ± 1.2
Slow compartment	2.4^{a} ± .4	3.3^{ab} ± .6	3.5^{ab} ± .4	4.3^{b} ± .6

[ab] Values with different superscript in each row differ ($P<.01$).

[c] DMO = dry matter output.

slow compartment, compared with unsupplemented steers (Table 4-13).

The time spent in the rumen by the particulate fraction is related to the time available for ruminal digestion, longer rumen retention time will increase total digestibility and reduce bypass (Owens and Isaacson, 1979). The lower rumen retention time recorded with all three concentrates suggests that digestion of fiber of small and large particles of hay would be depressed, as compared to unsupplemented steers. However, the higher total diet OM and NDF digestibilities in the rumen of supplemented steers, compared to unsupplemented steers (Tables 4-5 and 4-6), suggest that concentrates did not interfere hay digestion.

The lower total fill of undigested DM recorded by SBH in both small and large particles, compared to CSBM and WM supplemented steers, suggests that rumen capacity was not affected by SBH supplementation. This result agrees with Martin and Hibberd (1990), who mentioned that ruminal distension in SBH supplemented cattle is not the major factor limiting hay intake. Similar total fill of undigested DM in small and large particles in SBH supplemented steers, compared to unsupplemented steers, indicates a positive associative effect produced by SBH were an increase in total DOMI was obtained without a reduction in forage intake.

Ammonia concentration. Rumen liquid ammonia concentration (mg dL), was greater for wheat middlings (Table 4-14) than for other treatments with peak concentrations two hours after feeding (Figure 4-1). The higher value observed was in agreement with the high crude protein content of this concentrate (Table 4-2).

Table 4-14. Least square means for ammonia and PUN concentration.

Treatment	Ammonia (mg dL)	PUN (mg dL)
Control	$2.59^a \pm 1.10$	$3.85^c \pm 0.99$
CSBM	$1.68^a \pm 1.27$	$5.53^c \pm 1.14$
WM	$8.00^b \pm 1.10$	$8.65^d \pm 0.99$
SBH	$3.65^a \pm 1.27$	$5.50^c \pm 1.14$

[ab] Values with different superscript in each column differ (P<.01)

[cd] Values with different superscript in each column differ (P<.05)

Ammonia concentration changed over time (P=.01) and was different among concentrates at 2 (P=.0007), 4 (P=.0004), 6 (P=.003), 8 (P=.0001), 12 (P=.001), 18 (P=.008) and 24 (P=.04) hours postfeeding (Table A4-2). The curve fit over time was described by a quadratic (P=.0001) function (Figure 4-1). The same pattern of ammonia concentration through the day occurred for all animals fed concentrate supplements.

The highest values were present at 2 h after concentrate consumption, then a constant decline in ammonia

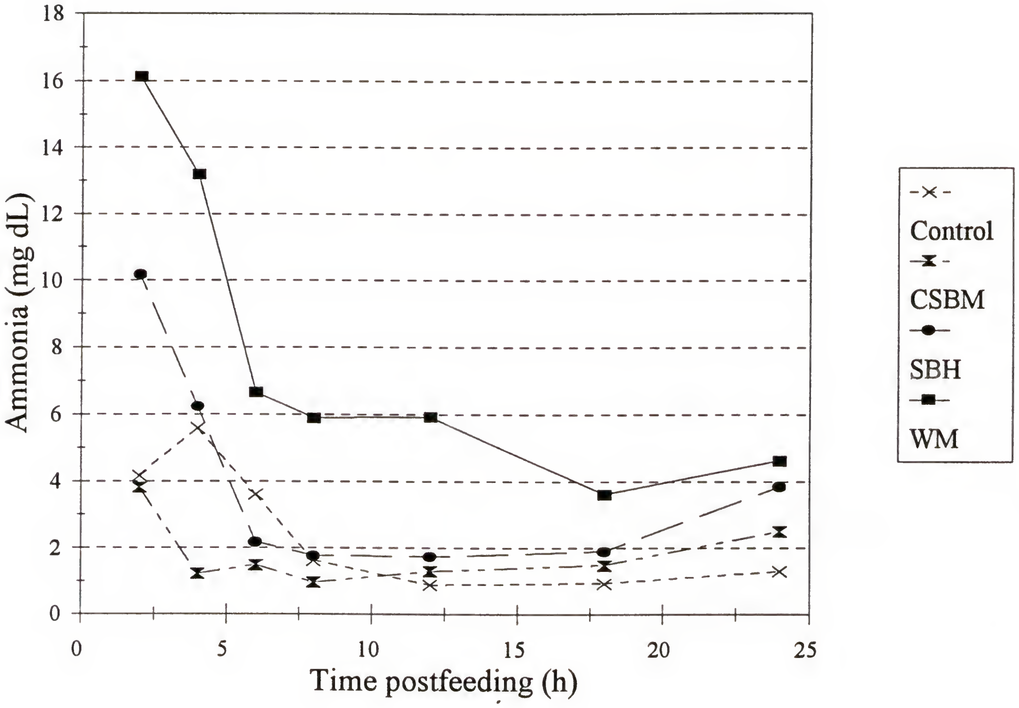

Figure 4-1. Diurnal variation of rumen liquid ammonia concentration (mg dL) for steers fed different concentrate sources.

concentration occurred and lower levels were maintained during the rest of the day. Control animals showed peak of ammonia concentration at 4 hours postfeeding, then rumen ammonia declined and was the lowest of all treatments at 12, 16 and 24 h (Figure 4-1).

Rumen ammonia concentrations for control (2.59 mg dL), CSBM (1.68 mg dL) and SBH (3.65 mg dL) supplementation treatments were below the minimum recommended levels (2 to 5 mg dL) for maximum microbial growth (Satter and Slyter, 1974). However, the low levels of ammonia in CSBM and SBH supplemented steers did not result a significant limitation to the fiber digesting bacteria because the NDF digestion rate of hay in nylon bags was increased in steers fed all concentrate supplements (Table 4-10). For both supplements, NDF digestion in the rumen was 7% higher than control (Table 4-6).

Levels of rumen fluid ammonia concentration are related to degradation of protein from supplements in rumen. Zinn and Owens (1983) reported that rumen degradation of corn protein is low. Therefore, it is possible that little ruminally available N was supplied by CSBM.

In addition, ammonia concentration is affected by type of supplement. Highfill et al. (1987) observed lower rumen concentrations of ammonia at most sampling times in cattle consuming low quality fescue hay supplemented with SBH compared to cattle fed corn based concentrate.

Supplementation with corn has produced low rumen ammonia concentrations (2.5 mg dL) in beef cows consuming bermudagrass hay (Brake et al. 1989). Sanson and Clanton (1989), and Chase and Hibberd (1989), also reported low rumen ammonia concentrations (1.8 mg dL) when steers consuming low quality meadow hay were supplemented with various levels of shelled corn. In both cases, authors suggested that the lack of ammonia may have depressed digestibility of their diets.

In agreement with these reports, Hibberd et al. (1987) suggested that feeding grain with low quality forage diets appears to create a large demand for ammonia in the rumen, and that ammonia may be rapidly assimilated by starch digesting bacteria leaving the fiber digesting bacteria deficient.

The low rumen ammonia concentration in SBH supplemented cattle may be an indication of a higher rate of fermentation and microbial growth and a greater uptake of ammonia by rumen microorganisms (Grisby et al., 1992). They reported that increased levels of soybean hull supplementation decreased rumen ammonia concentrations compared to unsupplemented steers (5, 3.8, 3.4, 2.6 and 2.6 mM for 0, 15, 30, 45 and 60% SBH diets) consuming low quality brome grass hay.

The same response in low rumen ammonia concentration with increased SBH levels was reported by Martin and Hibberd

(1990). They reported <1 mg dL of rumen ammonia after 6 h postfeeding when SBH was supplemented at .22, .44 or .66 % BW. They suggested that SBH protein may be rapidly degraded resulting in lower rumen ammonia concentrations throughout the day.

Scott and Hibberd (1990) reported rumen ammonia concentrations below 1 mg dL for beef cows consuming low quality native grass hay and in cows supplemented with .35% BW soybean hulls. The same response was reported by Trautman et al. (1987) in beef cows supplemented with .64% BW soybean hulls that were fed low quality native grass hay. Ammonia concentrations for unsupplemented and cows supplemented with SBH fed were 5.8 and 2.1 mg dL, respectively.

Compared to unsupplemented cattle, higher ammonia concentration in the rumen has been reported for cattle supplemented with WM (Sunvold et al., 1991; Arelovich et al., 1983). In both cases higher CP concentration in the supplements was suggested as the reason the higher rumen ammonia.

Plasma urea nitrogen (PUN) was higher (P=.05) in WM supplemented steers, compared to all other treatments (Table 4-14). Values for PUN reflected the ammonia concentration in rumen fluid, which were also higher for WM supplemented steers than all other treatments (Table 4-14).

In all treatments, PUN was below the recommended level of 11 to 15 mg dL (Byers and Moxon, 1980; Hammond, 1992), usually associated with good performance for growing cattle (Table 4-14). The low PUN levels were in agreement with the low CP concentration provided by the total diet.

Rumen fluid pH. Rumen fluid pH was decreased by WM and CSBM supplementation compared to unsupplemented and SBH supplemented steers (Table 4-15). Rumen pH was lowest for CSBM (6.15) at 4 hours postfeeding. All pH values were above 6.1, and they did not remain low for an extended period of time (Figure 4-2).

Table 4-15. Least square means for rumen liquid pH.

Treatment	pH
CONTROL	6.80[a] ± .08
CSBM	6.60[b] ± .09
WM	6.58[b] ± .08
SBH	6.72[a] ± .09

[ab] Values with different superscript differ ($P<.05$)

Rumen liquid pH changed ($P=.0008$) over time, and was different among treatments at 4 ($P=.006$), 6 ($P=.0002$) and 8 ($P=.07$) hours postfeeding (Table A4-3). The curve fit over time was described by a quadratic ($P=.0002$) function (Figure 4-2). The values recorded for pH did result in a depression in OM digestion in the rumen for CSBM and WM supplemented

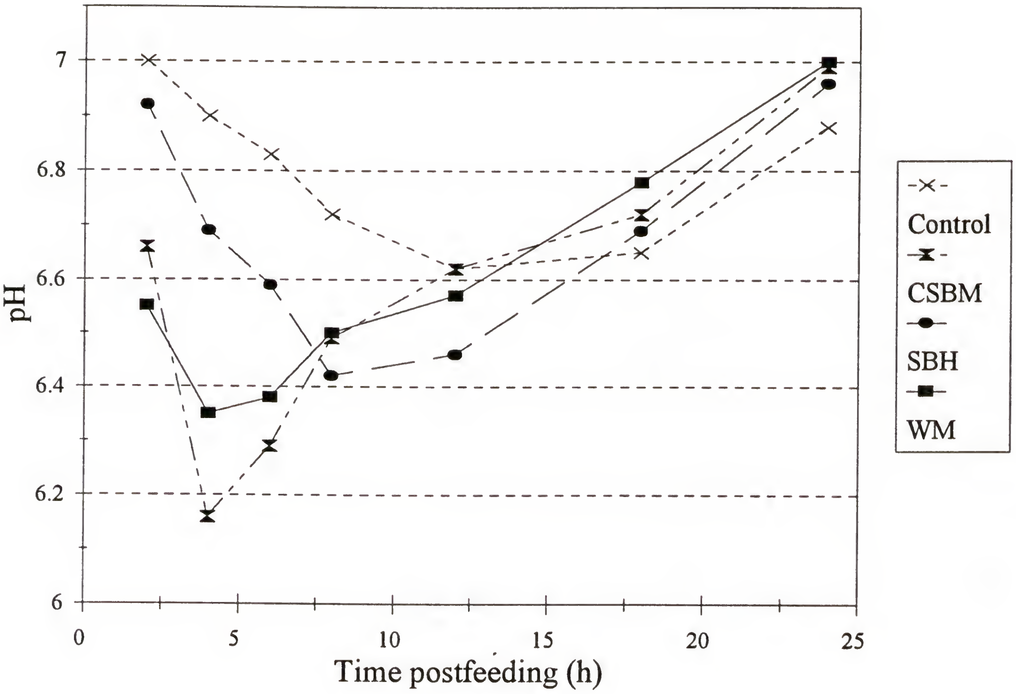

Figure 4-2. Diurnal variation of rumen liquid pH for steers fed different concentrate sources.

steers (estimated with chromium oxide), compared to SBH supplemented steers (Table 4-5).

Several authors have reported average pH values above 6.2 when corn, WM or SBH were supplemented to cattle consuming forage based diets (Galloway et al. 1993b; Sanson and Clanton 1989; Brake et al. 1989; Pordomingo et al. 1991; Chase and Hibberd, 1989; Hibberd et al. 1987; Chase and Hibberd, 1987; Grisby et al. 1992; Martin and Hibberd, 1990; Trautman et al. 1987; Sunvold et al. 1991).

Similar pH values for unsupplemented (6.64), corn (6.55) or SBH (6.54) supplemented steers consuming bermudagrass hay were reported by Galloway et al. (1993b). They suggested that lack of effects of diet on rumen liquid pH was due to the low level of supplementation (.28 and .39% BW for corn and SBH, respectively).

Sanson and Clanton (1989) reported that increased levels of corn in diet did not affect rumen fluid pH. Mean pH values were 6.6, 6.6, 6.4 and 6.4 for 0, .25, .50 and .75% BW of corn supplemented to steers consuming low quality meadow hay. These values did not have detrimental effects on fiber digestion.

Volatile fatty acids. All three concentrates increased (P=.05) total concentration of VFA in the rumen fluid (Table 4-16). Compared to unsupplemented steers, increase in total VFA concentration was 23.9, 33.7 and 38.8% greater for CSBM, WM and SBH supplemented steers, respectively.

Table 4-16. Least square means for total and molar proportions of VFA.

Treatment	Total VFA, mM	Acetate mol/100 mol	Propionate mol/100 mol	Butyrate mol/100 mol	A:P ratio
CONTROL	$58.5^{a} \pm 3.6$	$71.2^{d} \pm .6$	$18.8^{d} \pm .5$	$7.8^{d} \pm .2$	$3.94^{a} \pm .12$
CSBM	$72.5^{b} \pm 4.8$	$67.6^{e} \pm .7$	$21.1^{e} \pm .7$	$8.9^{e} \pm .3$	$3.34^{b} \pm .15$
WM	$78.6^{b} \pm 3.6$	$63.6^{f} \pm .6$	$24.0^{f} \pm .5$	$10.3^{f} \pm .2$	$2.68^{c} \pm .12$
SBH	$81.6^{b} \pm 4.8$	$70.5^{d} \pm .7$	$19.0^{d} \pm .7$	$8.7^{e} \pm .3$	$3.69^{a} \pm .15$

[abc] Values with different superscript in each column differ ($P<.05$).
[def] Values with different superscript in each column differ ($P<.01$).

The molar proportions of acetate and propionate were affected by concentrates (Table 4-16). Unsupplemented and SBH supplemented steers had higher (P=.01) molar proportions of acetate than CSBM and WM supplemented steers. Wheat middlings had the lowest molar proportion of acetate compared to other treatments (Table 4-16 and Figure 4-3).

Acetate concentration changed over time and was different among concentrates at 2 (P=.01), 4 (P=.01), 6 (P=.04) 8 (P=.01), 12 (P=.01) and 24 (P=.08) hours postfeeding (Table A4-4). The curve fit over time was described by a linear (P=.02) function (Figure 4-3).

Molar proportions of propionate were higher (P=.01) for WM than all other treatments, and CSBM supplemented steers had higher proportions than control (Table 4-16). In addition, CSBM had higher in molar proportions of propionate than SBH (Table 4-16 and Figure 4-4).

Propionate concentration changed over time and was different among concentrates at 2 (P=.04), 4 (P=.01), 6 (P=.09), 8 (P=.007), and 24 (P=.02) hours postfeeding (Table A4-5). The curve fit over time was described by a linear (P=.02) function (Figure 4-4).

These responses in molar proportions of acetate and propionate produced the lowest acetate to propionate ratio (A:P ratio) for WM, as compared to all other treatments (Table 4-16). Unsupplemented cattle had a higher A:P ratio compared to CSBM and WM supplemented steers. Compared to

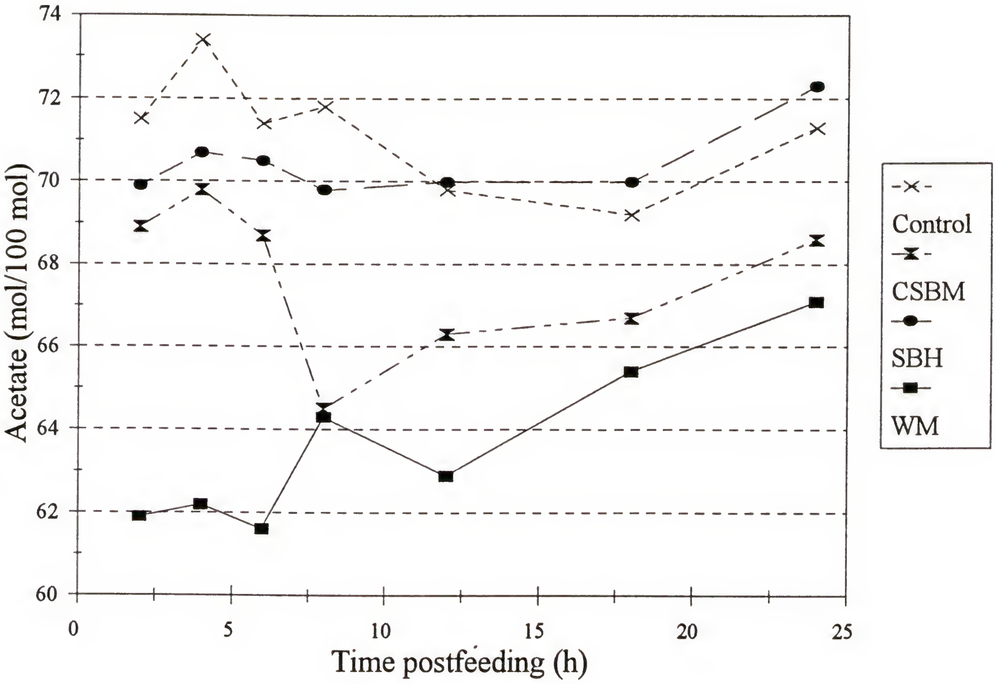

Figure 4-3. Diurnal variation in molar proportions of acetate for steers fed different concentrate sources.

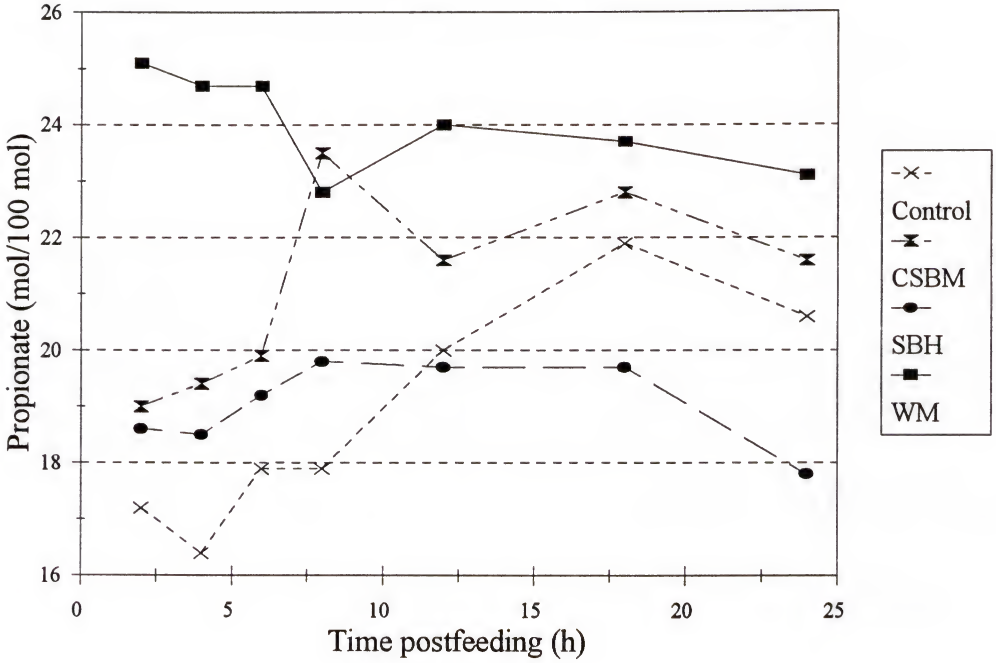

Figure 4-4. Diurnal variation in molar proportions of propionate for steers fed different concentrate sources.

CSBM, SBH had a 9.5% higher in A:P ratio (Table 4-16 and Figure 4-5).

The acetate to propionate ratio changed over time and was different among concentrates at 2 (P=.04), 4 (P=.02), 6 (P=.07), 8 ((P=.01) and 24 (P=.02) hours postfeeding (Table A4-6). The curve fit over time was described by a linear (P=.02) function (Figure 4-5).

The higher total VFA (mM) concentration and the lower A:P ratio observed in supplemented steers, as compared to unsupplemented steers, may have contributed to the higher ADG when concentrates were fed in the performance trial with growing cattle. Compared to CSBM, the higher ADG in WM supplemented steers also may be related to its greater CP concentration and its lower A:P ratio.

Butyrate was also higher for WM, than other treatments, and lowest for unsupplemented cattle (Table 4-16). Butyrate concentration changed over time and was different among concentrates at 4 (P=.01) and 6 (P=.08) hours postfeeding (Table A4-7). The curve fit over time was described by a quadratic (P=.0002) function (Figure 4-6).

Chase and Hibberd (1989) reported an increase in the molar proportion of propionate and a decrease in the molar proportion of acetate in corn supplemented compared to unsupplemented beef cows consuming low quality native grass hay. However, the same authors in 1987 reported a decrease in the molar proportion of acetate with higher levels of

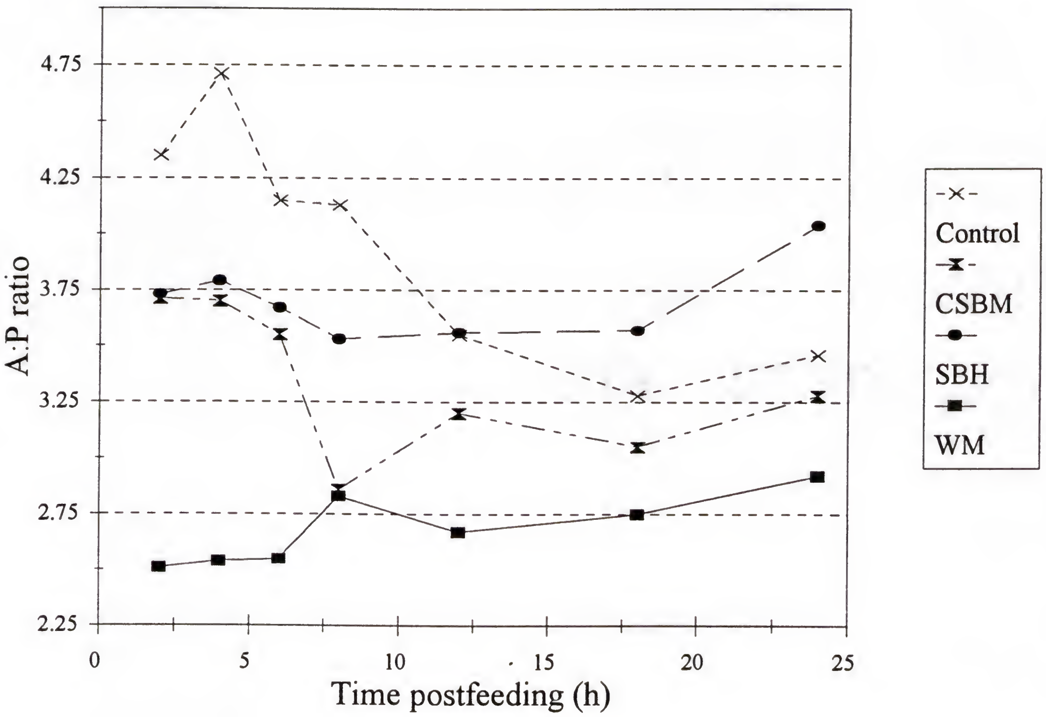

Figure 4-5. Diurnal variation of acetate to propionate ratio for steers fed different concentrate sources.

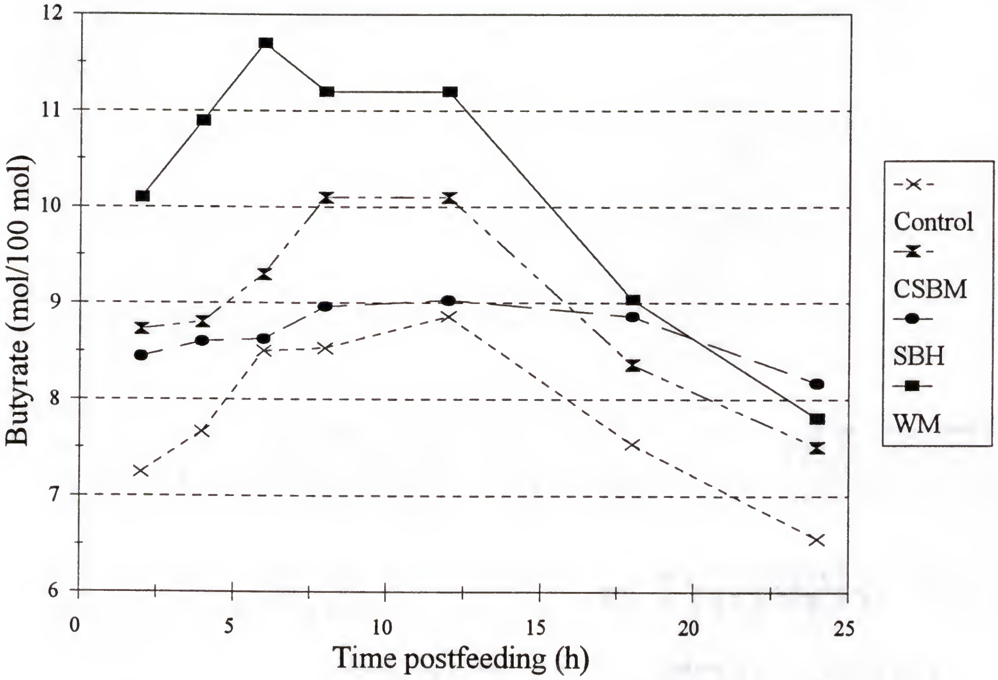

Figure 4-6. Diurnal variation in molar proportions of butyrate for steers fed different concentrate sources.

corn in diet and no change in propionate in beef cows fed low quality hay.

Sunvold et al. (1991) reported a decrease (P=.01) in molar proportions of acetate and a trend (P=.18) for higher molar proportions of propionate by steers fed increasing amounts (.39 and .77% BW) of wheat middlings and consuming tallgrass prairie forage. Molar proportions of acetate were 78.7, 73.9 and 70.9% for control, .39 and .77% BW of WM, and molar proportions of propionate were 15.4, 15.9 and 17.3% for control, .39 and .77% BW of WM. As a consequence of these molar proportions, the acetate to propionate ratio was lower (P=.08) at the high WM supplementation level (5.1, 4.7 and 4.2 for control, .39 and .77% BW of WM, respectively).

Results in this experiment also agree with Grisby et al. (1992) and Martin and Hibberd (1990), who reported a higher total VFA concentration with increasing SBH levels. In contrast to our study, Grisby et al. (1992) reported higher acetate proportions and lower propionate proportions with SBH supplementation. In contrast, Martin and Hibberd (1990) reported lower molar proportion of acetate but higher propionate, and consequently decreased A:P ratio with SBH supplementation.

Summary and Conclusions

Results of this trial suggest that concentrates supplements fed to cattle on hay based diets had different effects on the rumen environment of steers consuming bermudagrass hay. Steers fed SBH had the highest total NDF intake of all treatments, but had similar rumen NDF digestibilities compared to CSBM and WM, and higher NDF digestibility than unsupplemented steers. Effects of SBH supplementation on particle kinetics in the rumen explains higher steer ADG observed with this concentrate. Compared to CSBM and WM supplemented steers, steers supplemented with SBH had less total fill of small and large particles in rumen. In addition, SBH supplemented steers had faster rates of passage for small and large particles than unsupplemented steers.

The higher CP concentration in WM resulted in the highest rumen fluid ammonia concentration among treatments. Steers supplemented with WM also had the lowest A:P ratio. These two variable combined to provide adequate levels of energy and nitrogen for microbial growth which resulted in OM and NDF digestibilities similar to those found in the digestibility trial with sheep.

Rumen fluid pH and rumen ammonia concentration had no detrimental effects on fiber degradation of the base forage. Additionally, concentrates had no effect in OM and NDF digestion of the base forage.

CHAPTER V

SUMMARY AND CONCLUSIONS

Supplementation of cattle consuming bermudagrass hay ad libitum increased weight gains and body condition score. Shrunk weight gains for unsupplemented cattle were only 40% (0.30 kg d^{-1}) of shrunk weight gains for supplemented cattle (0.75 kg d^{-1}).

The higher level of supplementation produced higher (.87 kg d^{-1}) ADG than the lower (.63 kg d^{-1}) feeding level. Among concentrate sources, cattle weight gains were similar for all supplements at the low feeding level, but at the high feeding level cattle fed SBH had higher (.95 kg d^{-1}) weight gains than cattle fed CSBM (.76 kg d^{-1}). Similar hay intake, forage intake change and substitution rate among supplements, suggest different mechanisms involved in producing differences in ADG at the high feeding level.

Digestibility of NDF was higher in sheep fed SBH than CSBM or WM at both feeding levels. At the low feeding level, NDFD for SBH was 4 percentage units higher (58.9%) than CSBM (54.6%) and WM (54.6%), and at the high feeding level the NDFD percentage difference was 12 percentage units higher for SBH (63.3%) than CSBM (51.0%) and WM (51.8%).

The higher total tract NDFD for SBH explains partially the better performance of steers in this supplement.

The nylon bag trial showed that among concentrate sources, there were no differences in rumen digestion of hay NDF. These results suggest that the increase in total tract NDF digestion when SBH were supplemented, relates to increased intake of highly digestible NDF and not to increased NDF digestibility of the base forage.

The higher DOMI of SBH supplemented steers at the high level of supplementation resulted in the highest concentration of VFA's, and also explain the high ADG of cattle supplemented with this concentrate, because VFA produced in rumen provide 50 to 80% of the total metabolizable energy available for ruminants (Merchen and Bourquin, 1994).

Compared to unsupplemented steers, fill of undigested DM of small particles in the slow (rumination) compartment of rumen was lower (.48% BW) for SBH supplemented steers. In addition, steers supplemented with SBH had similar total fill of large particles compared to control steers (1.10 vs 1.06% BW for unsupplemented and SBH supplemented steers, respectively), but lower total fill of large particles than CSBM (1.27% BW) and WM (1.25% BW) supplemented steers. The lower fill of undigested DM of the forage in the rumen of SBH supplemented steers is related to the high intake of highly digestible NDF from SBH and may explain the statement made by Martin and Hibberd (1990) that ruminal distension in SBH supplemented animals is not the major factor limiting hay intake.

The higher ADG for WM (.90 kg d^{-1}) than CSBM (.76 kg d^{-1}) at the high feeding level was related to the higher CP concentration and the lower A:P ratio in WM, as compared to CSBM. The high CP concentration in WM increased (8.0 mg dL) rumen fluid ammonia concentration compared to CSBM (1.8 mg dL). In addition, WM produced the lowest (63.6%) molar proportion of acetate and the highest (24.0%) molar proportion of propionate. Consequently the A:P ratio was lower (2.65) for WM compared than CSBM (3.34).

Another factor that may contribute to higher ADG in SBH and WM supplemented steers was the increased rumen liquid turnover. Rumen liquid turnover was 7.96, 8.98, 9.54 and 9.64% h^{-1} for control, CSBM, WM and SBH supplemented cattle. The higher rumen liquid turnover rate is associated with increased ruminal outflow of soluble and small particulate feed components (Teeter and Owens, 1983).

Cattle fed WM had lower BCS than cattle fed CSBM or SBH at both feeding levels. At the low feeding level cattle fed WM lost BCS (-.23) while steers fed CSBM and SBH gained BCS (.65 and .23 for CSBM and SBH, respectively). At the high feeding level all three concentrates increased BCS, but WM supplemented steers gained less BCS than CSBM and SBH supplemented steers (.34, .13 and .61 increase in BCS for

CSBM, WM and SBH, respectively). The lower BCS recorded for WM supplemented cattle can not be explained by the proportions of VFA recorded, which had a different trend to the one expected in lean animals.

Blaxter (1962) and Minson (1990) mentioned that the higher proportion of acetic acid and the lower proportion of propionic acid in the digestion products reduce the efficiency of body fat synthesis. Although fat deposition is directly proportional to energy intake (McShane et al., 1989; Byers, 1982) other factors (intrinsic properties of grain and forages and effects of specific carbon sources on lipogenesis; Byers, 1982) may regulate fat accretion in cattle.

The possible explanation for differences in BCS change due to increased somatotropin (STH) secretion which could result in increased lean growth and reduced fat deposition (Davenport et al., 1990) needs to be addressed.

At the high level of supplementation feeds containing highly digestible fiber resulted in better animal performance than expected from their supplemental TDN intake. Based on this research, current recommendations for supplementing cattle on forage based diets are to purchase energy supplements based on the cost of TDN when supplements provide .25% body weight or less of starch. Starch intake at the low level of supplementation in performance trials was .25, .11 and .02% of BW for CSBM, WM and SBH supplemented steers, respectively.

When higher levels of performance are desired, then supplements high in digestible fiber and high in TDN, such as soybean hulls and WM are preferred. The high level of supplementation with WM and SBH did not provide high amounts of starch intake which often reduces forage digestion and animal performance (starch intake at the high level of supplementation was .54, .25 and .05% of BW for CSBM, WM and SBH supplemented steers, respectively). Contrary to the similar ADG expected from the similar TDN intake at the high level of supplementation of concentrates, steers supplemented with WM and SBH produced 18.4 and 25% more ADG, respectively, than CSBM supplemented steers.

APPENDIX

Table A3-1. Percentage of TDN intake from concentrates by animal, treatment and year.

YEAR	SOURCE	LEVEL	HAYTDNI[a]	CONCTDNI[b]	TDNCONC[c]
1	CONTROL	0	7.40	0.00	0.0
1	CONTROL	0	7.69	0.00	0.0
1	CONTROL	0	6.89	0.00	0.0
1	CONTROL	0	7.52	0.00	0.0
1	CONTROL	0	8.69	0.00	0.0
1	CONTROL	0	6.54	0.00	0.0
1	CONTROL	0	7.06	0.00	0.0
1	CONTROL	0	6.95	0.00	0.0
1	CSBM	25	8.16	2.66	24.6
1	CSBM	25	7.79	2.55	24.7
1	CSBM	25	5.63	2.05	26.7
1	CSBM	25	7.43	2.47	25.0
1	CSBM	50	7.47	6.58	46.9
1	CSBM	50	5.97	5.87	49.6
1	CSBM	50	4.78	4.94	50.8
1	CSBM	50	7.44	6.55	46.8
1	SBH	25	8.42	2.37	22.0
1	SBH	25	7.76	2.30	22.9
1	SBH	25	7.13	2.37	25.0
1	SBH	25	7.86	2.51	24.2
1	SBH	50	5.79	5.25	47.6
1	SBH	50	6.78	6.02	47.0
1	SBH	50	5.55	5.05	47.6
1	SBH	50	7.63	4.81	38.7
1	WM	25	7.91	2.60	24.7
1	WM	25	8.30	2.68	24.4
1	WM	25	6.61	2.31	25.9
1	WM	25	7.68	2.56	25.0
1	WM	50	6.70	5.92	46.9
1	WM	50	6.56	4.81	42.3
1	WM	50	7.06	6.56	48.2
1	WM	50	6.16	5.84	48.7

[a] HAYTDNI: intake of TDN from hay, kg.
[b] CONCTDNI: intake of TDN from concentrates, kg.
[c] TDNCONC: percentage of TDN intake from concentrates.

Table A3-1. Percentage of TDN intake from concentrates by animal, treatment and year. (Cont.)

YEAR	SOURCE	LEVEL	HAYTDNI[a]	CONCTDNI[b]	TDNCONC[c]
2	CONTROL	0	7.48	0.00	0.0
2	CONTROL	0	8.39	0.00	0.0
2	CONTROL	0	10.52	0.00	0.0
2	CONTROL	0	9.00	0.00	0.0
2	CONTROL	0	8.51	0.00	0.0
2	CONTROL	0	9.47	0.00	0.0
2	CONTROL	0	8.65	0.00	0.0
2	CSBM	25	9.15	2.79	23.4
2	CSBM	25	9.15	2.89	24.0
2	CSBM	25	9.64	3.00	23.7
2	CSBM	25	10.50	3.19	23.3
2	CSBM	50	6.68	6.05	47.5
2	CSBM	50	9.07	6.88	43.2
2	CSBM	50	8.80	7.35	45.5
2	CSBM	50	8.55	6.72	44.0
2	SBH	25	8.50	2.68	23.9
2	SBH	25	9.79	3.09	24.0
2	SBH	25	9.26	2.75	22.9
2	SBH	25	9.65	2.96	23.5
2	SBH	50	7.63	6.68	46.7
2	SBH	50	7.19	6.04	45.6
2	SBH	50	11.19	4.35	28.0
2	SBH	50	8.47	6.86	44.8
2	WM	25	9.44	3.88	29.1
2	WM	25	9.91	2.95	23.0
2	WM	25	11.27	3.23	22.3
2	WM	25	12.00	3.48	22.5
2	WM	50	8.16	7.26	47.1
2	WM	50	9.96	8.16	45.0
2	WM	50	7.54	6.87	47.7
2	WM	50	9.07	8.03	47.0

[a] HAYTDNI: intake of TDN from hay, kg.
[b] CONCTDNI: intake of TDN from concentrates, kg.
[c] TDNCONC: percentage of TDN intake from concentrates.

Table A3-2. Intake (kg d^{-1}) by cattle fed bermudagrass hay and supplemented with corn (CSBM), wheat middlings (WM) or soybean hulls (SBH) (Year 1).

	TREATMENT							
		LOW			HIGH			Pooled SEM
	CONTROL	CSBM	WM	SBH	CSBM	WM	SBH	
DM, kg d^{-1}								
Hay	5.75	5.68	5.98	6.11	5.03	5.18	5.04	.28
Concentrate	0	1.10	1.27	1.51	2.70	2.88	3.33	.11
Total	5.75	6.78	7.25	7.62	7.73	8.06	8.37	.33
OM, kg d^{-1}								
Hay	5.47	5.38	5.70	5.81	4.78	4.93	4.78	.27
Concentrate	0	1.06	1.15	1.40	2.61	2.63	3.10	.10
Total	5.47	6.44	6.85	7.21	7.39	7.56	7.88	.32
NDF, kg d^{-1}								
Hay	4.81	4.74	4.99	5.10	4.20	4.33	4.21	.23
Concentrate	0	0.18	0.5	0.89	0.43	1.14	1.96	.04
Total	4.81	4.92	5.49	5.99	4.63	5.47	6.17	.24
CP, kg d^{-1}								
Hay	0.55	0.54	0.57	0.6	0.48	0.49	0.49	.03
Concentrate	0	0.14	0.25	0.2	0.33	0.58	0.53	.02
Total	0.55	0.68	0.82	0.8	0.81	1.07	1.02	.04

Table A3-3. Intake (kg d^{-1}) by cattle fed bermudagrass hay and supplemented with corn (CSBM), wheat middlings (WM) or soybean hulls (SBH) (Year 2).

	TREATMENT							
		LOW			HIGH			Pooled SEM
	CONTROL	CSBM	WM	SBH	CSBM	WM	SBH	
DM, kg d^{-1}								
Hay	6.51	7.07	7.83	6.84	6.09	6.38	6.34	.35
Concentrate	0	1.37	1.73	1.82	3.11	3.87	3.79	.15
Total	6.51	8.44	9.56	8.66	9.20	10.25	10.13	.35
OM, kg d^{-1}								
Hay	6.11	6.63	7.34	6.41	5.71	5.99	5.95	.33
Concentrate	0	1.28	1.60	1.73	2.93	3.58	3.61	.14
Total	6.11	7.91	8.94	8.14	8.64	9.57	9.56	.33
NDF, kg d^{-1}								
Hay	5.06	5.48	6.08	5.31	4.72	4.95	4.92	.27
Concentrate	0	0.21	0.65	1.12	0.48	1.45	2.35	.08
Total	5.06	5.67	6.73	6.43	5.20	6.40	7.27	.26
CP, kg d^{-1}								
Hay	0.71	0.77	0.85	0.74	0.66	0.69	0.69	.04
Concentrate	0	0.17	0.32	0.23	0.39	0.72	0.47	.02
Total	0.71	0.94	1.17	0.97	1.05	1.41	1.16	.04

Table A3-4. Hay and concentrate intake (% BW) by growing steers.

	Treatment						
		Low			High		
	CONTROL	CSBM	WM	SBH	CSBM	WM	SBH
Year 1							
Hay	2.15	1.95	2.00	1.97	1.60	1.70	1.59
Suppl.	0.00	0.38	0.42	0.49	0.86	0.94	1.06
Total	2.15	2.33	2.42	2.46	2.46	2.63	2.66
Hay %		83.69	82.64	80.08	65.04	64.64	59.77
Suppl. %		16.31	17.36	19.92	34.96	35.74	39.85
F:C ratio	100:0	84:16	83:17	80:20	65:35	65:35	60:40
Year 2							
Hay	1.80	1.94	1.96	1.76	1.57	1.61	1.71
Suppl.	0.00	0.38	0.43	0.47	0.81	0.98	1.01
Total	1.80	2.32	2.39	2.23	2.38	2.59	2.72
Hay %		83.62	82.01	78.92	65.97	62.16	62.87
Suppl. %		16.38	17.99	21.08	34.03	37.84	37.13
F:C ratio	100:0	84:16	82:18	79:21	66:34	62:38	63:37
Average of both years							
Hay	1.98	1.95	1.98	1.87	1.59	1.65	1.65
Suppl.	0.00	0.38	0.43	0.48	0.83	0.96	1.04
Total	1.98	2.33	2.41	2.35	2.42	2.61	2.69
Hay %		83.69	82.16	79.57	65.70	63.22	61.34
Suppl. %		16.31	17.84	20.43	34.30	36.78	38.66
F:C ratio	100:0	84:16	82:18	80:20	66:34	63:37	61:39

Table A3-5. Dry matter intake (% BW) by sheep fed bermudagrass hay and supplemented with corn (CSBM), wheat middlings (WM), or soybean hull (SBH) in 1992 and 1993.

		Intake, (% BW, DM basis)		
Source	Level	Hay	Suppl	Total
CONTROL	0	2.01	---	2.01
CSBM	Low	1.87	0.37	2.24
WM	Low	1.84	0.41	2.25
SBH	Low	1.94	0.53	2.47
CSBM	High	1.58	0.89	2.47
WM	High	1.49	0.90	2.39
SBH	High	1.43	1.00	2.43
SEM				
CONTROL		0.08	-	0.1
CONCENTRATES		0.11	0.03	0.1
CONTRASTS, (P value)				
Control vs suppl.		0.0001	---	.0001
Low vs High		0.0001	0.0001	0.24
WM vs CSBM&SBH		0.59	0.11	0.35
CSBM vs SBH		0.48	0.44	0.75
WM vs CSBM&SBH/level		0.48	0.002	0.12
CSBM vs SBH/level		0.31	0.03	0.89

Table A3-6. Dry matter intake (% BW) by sheep fed bermudagrass hay and supplemented with corn (CSBM), wheat middlings (WM), or soybean hull (SBH) in Year 1.

		Intake, (% BW, DM basis)		
Source	Level	Hay	Suppl	Total
CONTROL	0	2.03	---	2.03
CSBM	Low	1.96	0.38	2.34
WM	Low	1.95	0.43	2.38
SBH	Low	2.02	0.55	2.57
CSBM	High	1.70	0.97	2.67
WM	High	1.67	0.98	2.65
SBH	High	1.56	1.13	2.69
SEM				
CONTROL		0.07	-	0.08
CONCENTRATES		0.10	0.03	0.11
CONTRASTS, (P value)				
Control vs suppl.		0.01	---	.0001
Low vs High		0.0004	0.0001	0.01
WM vs CSBM&SBH		0.57	0.12	0.39
CSBM vs SBH		0.50	0.56	0.88
WM vs CSBM&SBH/level		0.88	0.0001	0.21
CSBM vs SBH/level		0.48	0.0003	0.76

Table A3-7. Dry matter intake (% BW) by sheep fed bermudagrass hay and supplemented with corn (CSBM), wheat middlings (WM), or soybean hull (SBH) in Year 2.

		Intake, (% BW, DM basis)		
Source	Level	Hay	Suppl	Total
CONTROL	0	1.99	---	1.99
CSBM	Low	1.78	0.35	2.13
WM	Low	1.73	0.39	2.12
SBH	Low	1.88	0.51	2.39
CSBM	High	1.45	0.81	2.26
WM	High	1.31	0.82	2.13
SBH	High	1.29	0.86	2.15
SEM				
CONTROL		0.08	-	0.09
CONCENTRATES		0.11	0.05	0.13
CONTRASTS, (P value)				
Control vs suppl.		.0001	---	.09
Low vs High		.0001	.0001	.77
WM vs CSBM&SBH		.74	.20	.46
CSBM vs SBH		.64	.97	.72
WM vs CSBM&SBH/level		.36	.10	.18
CSBM vs SBH/level		.36	.43	.66

Table A3-8. Total tract organic matter digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 1.

		Organic matter intake g d^{-1}					
Source	Level	Hay	Suppl	Total	Feces, g d^{-1}	Digestible OMI g d^{-1}	OMD, %
CONTROL	0	870	0	870	416	454	51.9
CSBM	Low	905	179	1084	465	619	57.1
WM	Low	880	183	1063	475	588	55.4
SBH	Low	885	242	1127	470	657	58.3
CSBM	High	759	441	1200	440	760	63.1
WM	High	766	426	1192	510	682	57.1
SBH	High	760	549	1309	474	835	63.8
SEM							
CONTROL		26	-	36	14	23	0.7
CONCENTRATES		40	14	50	23	32	1.0
CONTRASTS, (P value)							
Control vs suppl.		.20	.0001	.0001	.003	.0001	.0001
Low vs High		.0006	.0001	.001	.78	.0001	.0001
WM vs CSBM&SBH		.99	.76	.92	.17	.26	.01
CSBM vs SBH		.76	.002	.21	.61	.10	.21
WM vs CSBM&SBH/level		.84	.0001	.19	.18	.004	.0001
CSBM vs SBH/level		.78	.01	.38	.33	.49	.63

Table A3-9. Total tract organic matter digestibility by sheep fed bermudagrass hay and supplemented with corn-soybean meal (CSBM), wheat middlings (WM), or soybean hulls (SBH) in Year 2.

		Organic matter intake g d^{-1}					
Source	Level	Hay	Suppl	Total	Feces, g d^{-1}	Digestible OMI, g d^{-1}	OMD, %
CONTROL	0	1151	0	1151	546	605	52.6
CSBM	Low	1050	208	1258	534	724	57.7
WM	Low	1009	225	1234	566	668	54.2
SBH	Low	1052	288	1340	587	753	56.1
CSBM	High	853	478	1331	508	823	62.0
WM	High	718	441	1159	500	659	56.7
SBH	High	765	512	1277	496	781	61.2
SEM							
CONTROL		40	-	47	32	28	0.5
CONCENTRATES		56	36	66	46	39	0.7
CONTRASTS, (P value)							
Control vs suppl.		.0001	.0001	.04	.58	.0003	.0001
Low vs High		.0001	.0001	.69	.01	.22	.0001
WM vs CSBM&SBH		.49	.67	.66	.51	.21	.0008
CSBM vs SBH		.67	.71	.81	.48	.88	.08
WM vs CSBM&SBH/level		.26	.002	.04	.46	.006	.0003
CSBM vs SBH/level		.26	.26	.55	.75	.21	.005

Table A4-1. Hay and concentrate intakes by steers during sampling phase.

Period	Steer[a]	Treatment	Hay intake, kg d^{-1}	Concentrate intake, kg d^{-1}
1	1	CSBM	7.5	3.8
1	2	WM	5.9	3.8
1	3	SBH	7.2	4.5
1	4	CONTROL	8.3	0.0
2	1	WM	6.7	4.8
2	2	CONTROL	4.9	0.0
2	3	CSBM	7.6	3.8
2	4	SBH	7.4	4.0
3	1	SBH	7.0	4.2
3[b]	2	CSBM	2.9	2.4
3	3	CONTROL	8.3	0.0
3	4	WM	7.0	5.2
4	1	CONTROL	8.1	0.0
4[b]	2	SBH	3.9	1.9
4	3	WM	8.1	4.4
4	4	CSBM	7.7	4.2

[a] Steers BW (kg): 1) 505.3; 2) 424.1; 3) 501.7; 4) 438.2

[b] Data not included in final analyses.

Table A4-2. Least square means for diurnal variation of rumen liquid ammonia concentration.

Hours postfed	CONTROL	CSBM	WM	SBH	P
2	4.17	3.83	16.12	10.17	.0007
4	5.59	1.23	13.19	6.23	.0004
6	3.61	1.50	6.66	2.18	.003
8	1.63	0.97	5.89	1.77	.0001
12	0.90	1.31	5.92	1.74	.001
18	0.95	1.50	3.62	1.91	.008
24	1.31	2.51	4.62	3.85	.04
SE	0.86	1.02	0.86	1.02	

Treatment x time: quadratic (P=.0001)

Table A4-3. Least square means for diurnal variation of rumen liquid pH.

Hours postfed	CONTROL	CSBM	WM	SBH	P
2	7.00	6.66	6.55	6.92	.21
4	6.90	6.15	6.35	6.69	.006
6	6.83	6.29	6.37	6.59	.0002
8	6.73	6.49	6.50	6.42	.07
12	6.63	6.62	6.58	6.46	.56
18	6.65	6.72	6.78	6.69	.75
24	6.88	6.99	7.00	6.96	.18
SE	0.09	0.10	0.09	0.10	

Treatment x time: quadratic (P=.0005)

Table A4-4. Least square means for diurnal variation of molar proportions of acetate.

Hours postfed	Treatment CONTROL	CSBM	WM	SBH	P
2	71.5	68.9	61.9	69.9	.01
4	73.4	69.8	62.2	70.7	.01
6	71.4	68.7	61.6	70.5	.04
8	71.8	64.5	64.3	69.8	.01
12	69.8	66.3	62.9	70.0	.01
18	69.2	66.7	65.4	70.0	.26
24	71.3	68.6	67.1	72.3	.08
SE	1.1	1.3	1.1	1.3	

Treatment x time: linear (P=.02)

Table A4-5. Least square means for diurnal variation of molar proportions of propionate.

Hours postfed	CONTROL	CSBM	WM	SBH	P
	Treatment				
2	17.2	19.0	25.1	18.6	.04
4	16.4	19.4	24.7	18.5	.01
6	17.9	20.0	24.7	19.2	.09
8	17.9	23.5	22.8	19.8	.007
12	20.0	21.6	24.0	19.7	.29
18	21.9	22.8	23.7	19.7	.44
24	20.6	21.6	23.1	17.8	.02
SE	1.1	1.3	1.1	1.3	

Treatment x time: linear (P=.02)

Table A4-6. Least square means for diurnal variation of acetate to propionate ratio.

	Treatment				
Hours postfed	CONTROL	CSBM	WM	SBH	P
2	4.35	3.71	2.51	3.73	.04
4	4.71	3.70	2.54	3.79	.02
6	4.15	3.55	2.55	3.67	.07
8	3.55	2.86	2.83	3.53	.01
12	3.28	3.20	2.67	3.56	.11
18	3.46	3.05	2.75	3.57	.25
24	3.71	3.28	2.92	4.04	.02
SE	0.21	0.25	0.21	0.25	

Treatment x time: linear (P=.02)

Table A4-7. Least square means for diurnal variation of molar proportions of butyrate.

Hours postfed	Treatment CONTROL	 CSBM	 WM	 SBH	P
2	7.5	8.70	10.1	8.4	.12
4	7.7	8.8	10.9	8.6	.01
6	8.5	9.3	11.7	8.6	.08
8	8.5	10.0	11.2	9.0	.19
12	8.9	10.1	11.2	9.0	.16
18	7.5	8.4	9.0	8.8	.47
24	6.6	7.5	7.8	8.2	.68
SE	0.41	0.48	0.41	0.48	

Treatment x time: linear (P=.03)

Table A4-8. Codes for variables measured in experiments.

1. Intake and performance trial with steers.

HAYIDM = Hay intake as DM basis, kg d^{-1}.
CONCIDM = Concentrate intake as DM basis, kg d^{-1}.
FWT0 = Full weight at day 0 of experiment, kg.
FWT28 = Full weight at day 28 of experiment, kg.
FWT56 = Full weight at day 56 of experiment, kg.
FWT77 = Full weight at day 77 of experiment, kg.
FWT84 = Full weight at day 84 of experiment, kg.
SRK0 = Shrunk weight at day 0 of experiment, kg.
SRK77 = Shrunk weight at day 77 of experiment, kg.
SRK84 = Shrunk weight at day 84 of experiment, kg.
BCS1 = Body condition score at day 0 of experiment, 1 to 9.
BCS2 = Body condition score at end of experiment, 1 to 9.
PUN1 = Plasma urea nitrogen at day 0 of experiment, mg dL.
PUN2 = Plasma urea nitrogen at day 28 of experiment, mg dL.
PUN3 = Plasma urea nitrogen at day 56 of experiment, mg dL.
PUN4 = Plasma urea nitrogen at end of experiment, mg dL.

2. Digestibility trial with sheep.

BODYWT = Live body weight, kg.
HYDM = Daily average of DM intake from hay, g.
CODM = Daily average of DM intake from concentrates, g.
HYOM = Daily average of OM intake from hay, g.
COOM = Daily average of OM intake from concentrates, g.
ORDM = Daily average of orts, DM basis, g.
OROM = Daily average of orts, OM basis, g.
WSDM = Daily average of waste, DM basis, g.
WSOM = Daily average of waste, OM basis, g.
FEDM = Daily average of feces, DM basis, g.
FEOM = Daily average of feces, OM basis, g.
HYNDF = Daily average of NDF intake from hay, g.
CONDF = Daily average of NDF intake from concentrates, g.
ORNDF = Daily NDF average of orts, g.
WSNDF = Daily NDF average of waste, g.
FENDF = Daily NDF average of feces, g.

3. Rumen variables with steers.

PER = Period.
AN = Steer number.
TREAT = Treatments: Control, corn-soybean meal (CSBM), soybean hulls (SBH) and wheat middlings (WM).
TIME = Time after feeding when samples were obtained, h.
AMMONIA = Rumen liquid ammonia concentration, mg dL.
PH = Rumen liquid pH.
DYPPM = Dysprosium concentration, ppm.
YBPPM = Ytterbium concentration, ppm.
CZERO = initial marker concentration in slow compartment, ppm.
KPSLOW = passage rate in slow compartment, % h^{-1}.
TDELAY = time of first appearance of marker, h..
DOSE = amount of marker dosed, mg/kg.
FASTMRT = mean retention time in fast compartment, h.
SLOWMRT = slow mean retention time in slow compartment, h.
TRMRT = total rumen mean retention time, h.
DUODDMO = DM output from duodenum, % BW.
KPFASTC = passage rate in fast compartment, % h^{-1}.
FILLUDMS= fill of undigestible DM in slow compartment, % BW.
FILLUDMF= fill of undigestible DM in fast compartment, % BW.
TOTALFIL= fill of undigestible DM in rumen, % BW.
COPPM = Cobalt concentration, ppm.
SOLFRACP= Soluble fraction, %.
SLOWDFRP= Slowly, or potentially digestible fraction, %.
UNDIGFP = Undigestible fraction, %.
LAG = Lag time, h.
KD = Rate of digestion, % h^{-1}.
EXTDIG = Extent of digestion, %.
BAGWT = Nylon bag weight, g.
BAG+SWT = Nylon bag weight plus sample weight, g.
SMPLWT = Sample weight placed in bag (hay or concentrates), g.
DRYWT48 = Sample weight after bags were removed from rumen and dried at 55° C during 48 hours, g.
NDF%DM = Neutral detergent fiber of sample remaining in nylon bag, % DM basis.
TOTAL = Total VFA content in rumen liquid, mM.
ACETIC = Total acetate content in rumen fluid, mM.
PROPION = Total propionate content in rumen fluid, mM.
BUTYRIC = Total butyrate content in rumen fluid, mM.
OTHER = VFA different than acetate, propionate and butyrate. Included: isobutyrate, isovalerate, valerate, isocaproic acid, caproic acid and heptanoic acid.
CRDUC = Chromium concentration in duodenal contents, ppm.
DMDUC = Dry matter percentage in duodenal contents.
OMDUC = Organic matter percentage in duodenal contents.

NDFDUC = Neutral detergent fiber percentage in duodenal contents.
CRFEC = Chromium concentration in feces, ppm.
DMFEC = Dry matter percentage in feces.
OMFEC = Organic matter percentage in feces.
NDFFEC = Neutral detergent fiber percentage in feces.
HAYINT = Average daily intake of hay by steers during sampling phase, kg.
HIDM = Average daily intake of hay by steers during sampling phase, kg of DM.
HIOM = Average daily intake of hay by steers during sampling phase, kg of OM.
HINDF = Average daily intake of hay by steers during sampling phase, kg of NDF.
CONINT = Average daily intake of concentrates by steers during sampling phase, kg.
CIDM = Average daily intake of concentrates by steers during sampling phase, kg of DM.

CIOM = Average daily intake of concentrates by steers during sampling phase, kg of OM.
CINDF = Average daily intake of concentrates by steers during sampling phase, kg of NDF.

Data for intake and performance trial in Year 1.

SOURCE	LEVEL	HAYIDM	CONCIDM	FWT0	FWT28	FWT56	FWT84	SRK0	SRK84	BCS1	BCS2	PUN1	PUN2	PUN3	PUN4
CONTROL	0	12.79	0.00	608	616	640	668	566	630	4	4.8	12.4	9.4	6.4	14.4
CONTROL	0	13.24	0.00	618	634	674	696	578	632	4	4.2	16.8	14.1	9.8	15.2
CONTROL	0	11.90	0.00	672	638	654	664	620	622	5	4.5	13.8	11.8	7.3	16.6
CONTROL	0	12.99	0.00	610	640	664	660	554	610	5	5.2	8.1	12.2	7.9	16.1
CONTROL	0	15.05	0.00	664	648	668	690	606	646	4	3.5	13.7	9.0	6.9	17.2
CONTROL	0	11.30	0.00	700	686	702	704	662	668	7	5.0	10.8	11.4	7.3	14.1
CONTROL	0	12.21	0.00	560	550	580	600	514	556	5	3.5	14.0	11.4	7.6	13.7
CONTROL	0	12.03	0.00	532	538	552	586	498	538	4	3.5	15.2	13.7	12.5	17.1
CSBM	25	14.05	3.02	662	664	692	744	612	694	5	5.8	13.3	11.1	10.2	12.9
CSBM	25	13.47	2.90	640	642	698	760	588	702	4	5.8	12.6	7.1	6.2	15.2
CSBM	25	9.74	2.33	626	608	612	662	586	638	6	6.0	10.1	10.4	9.5	12.4
CSBM	25	12.86	2.81	630	652	708	778	574	720	4	5.5	10.3	7.3	5.7	10.1
SBH	25	14.53	3.71	682	724	732	788	620	726	5	5.5	15.8	10.4	10.3	17.0
SBH	25	13.39	3.60	716	744	762	806	656	754	5	6.2	16.9	12.6	7.8	14.1
SBH	25	12.36	3.71	712	720	760	810	652	752	5	5.2	16.2	11.0	8.3	17.1
SBH	25	13.59	3.92	662	674	726	750	614	706	6	5.8	16.7	9.4	5.3	13.2
WM	25	13.69	3.29	676	704	758	802	632	738	5	5.0	15.5	11.4	10.4	17.2
WM	25	14.33	3.39	722	736	804	868	664	806	5	5.5	13.5	11.9	9.4	18.0
WM	25	11.48	2.93	640	646	666	700	584	646	5	4.8	15.8	14.3	11.1	19.6
WM	25	13.25	3.24	622	616	646	706	566	654	6	5.0	11.1	6.3	4.2	13.4
CSBM	50	12.90	7.48	766	800	868	952	698	894	5	6.2	5.4	6.1	6.1	8.5
CSBM	50	10.31	6.67	652	684	750	816	598	760	5	6.0	6.1	6.8	6.6	7.8
CSBM	50	8.28	5.61	668	668	708	742	630	714	7	6.5	4.0	6.9	5.3	6.9
CSBM	50	12.88	7.44	596	632	678	756	558	708	6	6.8	7.5	7.3	6.6	12.3
SBH	50	10.00	8.21	630	658	716	788	586	742	5	6.5	18.4	17.3	9.3	16.1
SBH	50	11.70	9.40	656	712	786	852	596	796	5	6.8	18.2	12.9	8.7	13.8
SBH	50	9.61	7.89	594	640	672	756	552	698	5	5.8	14.2	10.7	6.4	12.4
SBH	50	13.15	7.51	772	812	886	972	708	894	6	6.5	18.1	12.2	7.6	16.5
WM	50	11.55	7.49	696	694	782	882	640	808	5	5.8	18.1	13.1	13.7	18.1
WM	50	11.35	6.09	650	670	720	820	594	750	5	5.2	15.1	8.9	7.9	13.3
WM	50	12.19	8.30	642	658	750	856	594	778	5	5.8	16.7	10.8	11.0	18.1
WM	50	10.65	7.39	582	610	662	756	536	710	6	5.5	19.8	11.4	13.7	21.5

Data for intake and performance trial in Year 2.

SOURCE	LEVEL	HAYIDM	CONCIDM	FWT0	FWT28	FWT56	FWT77	SRK0	SRK77	BCS1	BCS2	PUN1	PUN2	PUN3	PUN4
CONTROL	0	12.12	0.00	800	822	856	900	755	838	6.0	4.8	8.7	12.6	8.5	12.7
CONTROL	0	13.60	0.00	730	749	748	762	683	698	5.3	4.0	18.0	15.2	15.0	16.0
CONTROL	0	17.06	0.00	903	954	958	1004	848	928	5.8	4.2	12.2	11.4	11.3	13.0
CONTROL	0	14.60	0.00	779	805	846	887	730	826	5.1	5.2	15.7	12.3	10.9	14.6
CONTROL	0	13.79	0.00	843	830	884	958	770	862	5.5	5.2	10.6	7.7	11.7	13.8
CONTROL	0	15.35	0.00	817	813	846	868	757	810	5.5	5.5	12.9	11.4	10.7	17.6
CONTROL	0	14.03	0.00	854	871	888	948	790	866	5.4	5.0	14.4	13.9	12.2	14.9
CSBM	25	14.84	3.17	706	758	778	842	653	790	5.2	5.6	13.1	14.0	14.0	15.5
CSBM	25	14.84	3.28	841	873	910	970	773	900	5.2	5.4	4.9	9.4	8.9	10.7
CSBM	25	15.64	3.41	787	854	870	924	728	862	5.3	5.7	9.3	9.2	9.6	8.6
CSBM	25	17.03	3.62	882	938	962	982	817	920	5.8	5.9	8.3	9.2	12.4	10.1
SBH	25	13.78	4.18	888	920	900	964	832	890	6.0	5.5	11.8	10.2	10.3	14.3
SBH	25	15.87	4.83	910	938	1010	1044	841	964	5.5	5.4	7.9	12.1	13.4	16.5
SBH	25	15.01	4.30	815	863	890	952	743	884	5.2	5.4	8.7	10.1	9.6	10.1
SBH	25	15.64	4.63	830	875	928	982	779	918	5.3	5.8	8.5	7.4	8.5	12.0
WM	25	15.30	4.91	893	927	984	1034	832	954	5.3	4.8	10.5	12.6	14.4	12.9
WM	25	16.06	3.74	841	862	904	962	770	888	5.8	5.2	12.6	13.8	11.8	19.8
WM	25	18.27	4.09	824	871	900	972	757	898	5.5	5.2	8.4	11.0	11.1	14.0
WM	25	19.45	4.41	982	995	1051	1116	912	1048	5.5	5.8	12.1	9.4	15.0	16.6
CSBM	50	10.82	6.87	788	817	870	914	732	852	5.8	5.9	7.7	10.2	11.5	12.9
CSBM	50	14.70	7.82	869	897	978	1008	802	938	5.5	5.6	8.7	16.3	14.9	14.5
CSBM	50	14.27	8.35	843	886	912	972	792	908	5.8	5.8	7.3	12.4	12.8	11.5
CSBM	50	13.87	7.64	908	950	980	1032	839	950	5.5	5.5	4.8	8.2	7.1	8.8
SBH	50	12.38	10.43	854	910	970	1052	805	952	5.4	6.0	9.9	8.4	8.1	14.5
SBH	50	11.66	9.43	798	845	906	972	728	890	5.7	6.0	10.7	9.9	10.2	13.7
SBH	50	18.15	6.80	740	807	856	938	678	860	5.7	5.4	9.3	7.1	7.6	11.4
SBH	50	13.73	10.72	809	877	964	1010	758	926	5.8	5.5	13.1	8.3	8.5	18.9
WM	50	13.24	9.19	863	888	960	1016	794	934	5.5	5.4	14.2	16.2	17.1	18.7
WM	50	16.14	10.33	918	991	1046	1106	845	1020	5.5	5.2	17.3	25.2	21.0	27.8
WM	50	12.22	8.70	783	833	892	942	719	866	5.5	5.3	14.1	14.0	15.2	18.3
WM	50	14.70	10.16	901	940	994	1044	826	958	5.2	5.5	14.1	15.5	15.2	17.8

Data for digestibility trial in Year 1.

PER	SOURCE	LEVEL	BODYWT	HYDM	CODM	HYOM	COOM	ORDM	OROM	WSDM
1	CONTROL	0	51.3	1076.4	0.0	1017.2	0.0	281.9	268.1	8.3
1	CONTROL	0	45.9	1026.3	0.0	972.9	0.0	197.5	188.3	23.6
1	CONTROL	0	41.8	1076.4	0.0	1017.2	0.0	278.2	264.8	13.5
1	CONTROL	0	44.0	1100.8	0.0	1038.1	0.0	313.1	296.8	7.3
1	CONTROL	0	47.7	1435.2	0.0	1356.3	0.0	219.0	207.8	66.7
1	CONTROL	0	45.4	1260.0	0.0	1192.0	0.0	271.0	256.6	47.1
2	CONTROL	0	40.0	1288.6	0.0	1235.7	0.0	259.4	248.0	13.1
2	CONTROL	0	53.6	1310.1	0.0	1253.8	0.0	449.3	427.2	17.7
2	CONTROL	0	41.8	1128.5	0.0	1081.1	0.0	242.7	230.4	19.0
2	CONTROL	0	44.0	1154.5	0.0	1104.8	0.0	161.5	155.0	40.3
2	CONTROL	0	45.4	1302.9	0.0	1249.5	0.0	220.4	208.7	20.3
2	CONTROL	0	44.0	1488.4	0.0	1425.9	0.0	324.1	307.6	198.2
1	CSBM	25	45.4	1205.9	167.7	1142.0	162.7	226.4	213.5	43.8
1	CSBM	25	56.3	1372.7	197.3	1299.9	191.3	313.2	296.3	76.8
1	CSBM	25	46.8	1351.5	199.0	1278.5	193.0	244.1	230.4	75.5
2	CSBM	25	50.8	1269.8	205.1	1215.2	198.9	213.9	202.4	49.2
2	CSBM	25	45.9	1230.9	188.6	1178.0	182.9	241.4	228.9	71.7
2	CSBM	25	46.8	994.4	147.7	953.6	143.3	171.4	164.3	7.9
1	CSBM	50	43.1	1031.6	430.2	975.8	417.3	295.3	279.4	12.9
1	CSBM	50	48.1	986.7	409.3	932.4	397.0	167.6	157.6	89.7
1	CSBM	50	47.7	1155.9	498.8	1091.1	483.8	420.0	395.6	104.9
2	CSBM	50	44.5	1089.6	424.1	1042.7	411.3	181.6	173.8	16.1
2	CSBM	50	49.5	1307.2	551.8	1253.6	535.3	273.1	260.5	54.2
2	CSBM	50	47.2	1087.2	417.1	1043.7	404.6	247.5	234.8	24.8
1	SBH	25	50.4	987.8	239.8	941.4	227.8	253.2	240.1	15.6
1	SBH	25	42.7	1347.0	294.8	1277.0	280.1	239.0	225.7	89.0
1	SBH	25	48.1	1345.5	270.0	1271.5	256.5	297.2	280.3	20.1
2	SBH	25	43.1	998.8	195.4	957.8	185.6	197.9	189.4	20.1
2	SBH	25	47.7	1371.9	261.1	1315.7	248.0	260.0	246.2	116.9
2	SBH	25	44.9	1323.1	268.2	1268.8	254.8	265.8	252.2	47.5
1	SBH	50	49.9	1167.4	657.1	1110.2	624.3	283.6	267.7	68.8
1	SBH	50	54.0	1078.8	688.2	1019.5	653.8	188.8	178.1	20.6
1	SBH	50	50.4	1014.6	579.9	956.8	550.9	184.3	174.0	89.8
2	SBH	50	48.1	903.0	448.4	866.0	426.0	162.0	155.3	36.6
2	SBH	50	53.6	1175.2	610.1	1125.8	579.6	260.9	248.9	21.3
2	SBH	50	49.0	1089.6	484.0	1046.0	459.8	307.7	293.2	25.0
1	WM	25	51.3	1502.6	259.1	1429.0	231.1	347.3	327.5	30.5
1	WM	25	43.6	1207.2	182.1	1140.8	162.4	285.7	270.0	9.9
1	WM	25	44.5	1388.6	218.0	1317.8	194.5	298.2	280.6	230.7
2	WM	25	49.0	1232.3	205.2	1180.5	183.0	262.5	250.4	24.4
2	WM	25	44.9	1116.8	173.6	1071.0	154.8	284.7	270.8	27.6
2	WM	25	49.5	1180.4	193.2	1132.0	172.4	228.1	218.0	72.8
1	WM	50	41.3	1076.4	477.9	1025.8	426.3	165.0	155.7	22.2
1	WM	50	46.3	1143.0	539.5	1084.7	523.3	281.0	264.7	86.4
1	WM	50	44.0	1077.6	480.5	1020.5	428.6	197.4	187.5	37.7
2	WM	50	53.1	993.3	417.2	954.6	372.2	167.3	160.1	13.0
2	WM	50	51.8	1043.7	427.5	1000.9	381.3	376.8	359.9	16.8
2	WM	50	55.8	1141.5	472.8	1094.7	421.8	254.4	242.4	49.9

Data for digestibility trial in Year 1 (Cont).

PER	SOURCE	LEVEL	WSOM	FEDM	FEOM	HYNDF	CONDF	ORNDF	WSNDF	FENDF
1	CONTROL	0	7.6	387.2	362.8	850.4	0.0	224.4	6.3	291.5
1	CONTROL	0	22.2	421.3	387.6	815.9	0.0	157.4	18.6	305.9
1	CONTROL	0	12.9	397.0	368.0	869.7	0.0	228.7	11.0	289.4
1	CONTROL	0	6.9	435.1	408.1	882.8	0.0	254.2	5.9	331.6
1	CONTROL	0	62.7	542.9	507.7	1138.1	0.0	176.5	52.6	412.1
1	CONTROL	0	44.0	461.0	431.5	996.7	0.0	217.1	37.0	355.0
2	CONTROL	0	12.3	517.6	486.0	1100.4	0.0	219.7	10.8	378.3
2	CONTROL	0	16.5	388.5	355.5	1084.8	0.0	360.8	14.7	268.8
2	CONTROL	0	17.8	423.6	396.5	941.2	0.0	194.4	15.7	293.5
2	CONTROL	0	38.2	446.6	414.5	960.5	0.0	135.8	33.9	307.7
2	CONTROL	0	19.2	521.4	481.3	1090.5	0.0	177.2	17.3	366.0
2	CONTROL	0	186.9	426.2	398.5	1208.6	0.0	269.6	160.7	292.4
1	CSBM	25	41.4	526.3	491.6	969.5	18.6	180.2	35.3	394.7
1	CSBM	25	72.1	525.9	493.8	1092.6	21.9	256.8	60.6	395.4
1	CSBM	25	70.2	548.5	515.0	1075.8	22.1	190.4	58.3	410.3
2	CSBM	25	44.7	510.9	471.6	1067.9	22.8	170.7	37.4	351.0
2	CSBM	25	66.7	462.1	429.3	1029.1	20.9	191.9	57.7	324.8
2	CSBM	25	7.5	416.9	386.1	842.3	16.4	144.6	6.7	295.6
1	CSBM	50	12.2	476.4	439.2	827.3	47.7	236.3	10.3	343.5
1	CSBM	50	84.8	479.0	447.8	781.5	45.4	133.4	72.9	346.3
1	CSBM	50	97.8	428.6	395.2	917.8	55.4	329.3	81.3	299.6
2	CSBM	50	15.0	450.6	411.0	915.3	47.1	150.3	13.3	300.1
2	CSBM	50	51.2	570.2	526.9	1075.8	61.3	225.3	45.5	384.9
2	CSBM	50	23.1	463.2	425.7	883.9	46.3	198.7	20.0	311.3
1	SBH	25	14.7	388.4	361.6	782.3	169.8	199.6	12.2	288.2
1	SBH	25	81.3	577.8	539.1	1084.3	208.7	193.4	68.9	431.1
1	SBH	25	18.5	565.8	527.3	1089.9	191.1	242.2	15.3	426.6
2	SBH	25	19.0	452.1	417.3	830.0	137.9	165.9	17.0	311.5
2	SBH	25	110.7	519.1	479.1	1127.7	184.3	205.1	96.5	363.4
2	SBH	25	44.8	530.6	497.7	1055.8	189.3	203.8	39.6	372.5
1	SBH	50	63.6	546.8	510.1	928.1	465.2	222.6	53.7	402.4
1	SBH	50	19.5	614.7	573.5	855.5	487.2	146.5	16.3	456.1
1	SBH	50	84.0	502.8	467.6	806.6	410.5	146.7	70.3	362.5
2	SBH	50	34.7	410.4	380.9	763.0	316.6	136.7	30.5	278.7
2	SBH	50	20.3	528.5	489.4	984.8	430.7	215.0	18.0	366.8
2	SBH	50	23.1	458.8	424.3	893.5	341.7	253.5	20.1	309.2
1	WM	25	28.8	686.9	630.6	1194.6	110.4	269.1	24.3	513.8
1	WM	25	9.4	479.2	439.5	974.2	77.6	230.6	8.1	351.3
1	WM	25	214.7	521.7	475.8	1105.3	92.9	238.0	182.7	379.8
2	WM	25	23.0	495.8	454.7	1025.3	87.4	216.0	20.4	340.6
2	WM	25	26.1	465.9	420.7	902.4	73.9	236.6	23.5	315.9
2	WM	25	69.1	474.1	430.5	971.5	82.3	193.4	61.7	321.5
1	WM	50	20.5	579.1	520.0	843.9	203.6	130.8	17.2	428.0
1	WM	50	81.0	584.8	521.1	929.3	229.8	220.6	67.8	418.2
1	WM	50	35.4	621.7	554.6	862.1	204.7	158.7	29.9	433.3
2	WM	50	12.4	538.9	472.6	822.5	177.7	141.6	11.2	349.8
2	WM	50	15.7	531.8	477.6	886.1	182.1	313.5	14.0	359.5
2	WM	50	47.2	586.2	515.3	955.4	201.4	208.3	41.2	382.2

Data for digestibility trial in Year 2.

PER	SOURCE	LEVEL	BODYWT	HYDM	CODM	HYOM	COOM	ORDM	OROM	WSDM
1	CONTROL	0	53.6	1909.3	0.0	1787.1	0.0	385.6	361.3	22.1
1	CONTROL	0	70.4	1795.3	0.0	1676.8	0.0	367.7	344.9	27.9
1	CONTROL	0	59.5	1839.1	0.0	1725.1	0.0	354.5	331.1	31.1
1	CONTROL	0	52.7	1427.2	0.0	1335.9	0.0	304.3	283.9	24.9
1	CONTROL	0	62.2	1513.0	0.0	1417.7	0.0	574.1	533.9	27.7
1	CONTROL	0	64.5	1494.3	0.0	1398.6	0.0	280.3	265.7	26.6
2	CONTROL	0	60.8	1599.6	0.0	1508.4	0.0	387.2	363.6	74.6
2	CONTROL	0	65.8	1530.0	0.0	1444.3	0.0	259.1	242.7	38.4
2	CONTROL	0	59.5	1465.7	0.0	1392.4	0.0	287.7	267.5	73.3
2	CONTROL	0	71.3	1581.4	0.0	1496.0	0.0	256.2	239.8	38.6
2	CONTROL	0	65.8	1456.0	0.0	1378.8	0.0	189.8	178.8	27.6
2	CONTROL	0	55.8	1747.3	0.0	1649.4	0.0	355.3	334.7	276.8
1	CSBM	25	63.1	1656.6	247.3	1548.9	231.7	370.1	347.2	43.7
1	CSBM	25	78.1	1366.5	219.5	1275.0	205.7	373.8	348.4	10.7
1	CSBM	25	63.1	1141.7	205.2	1068.6	192.3	377.3	353.9	16.5
2	CSBM	25	59.5	1547.0	233.9	1463.5	219.1	187.2	178.1	30.5
2	CSBM	25	61.7	1538.5	215.0	1453.9	201.5	277.7	260.7	64.2
2	CSBM	25	57.7	1470.4	215.9	1383.6	202.3	213.1	202.3	54.2
1	CSBM	50	63.6	1183.8	418.4	1108.0	392.1	366.2	340.2	36.0
1	CSBM	50	60.4	1084.4	438.1	1015.0	410.5	280.9	261.2	21.4
1	CSBM	50	65.8	1093.4	496.4	1021.3	465.1	462.7	432.2	17.4
2	CSBM	50	58.1	1393.2	506.2	1312.4	474.3	240.0	227.0	59.0
2	CSBM	50	67.6	1483.6	623.6	1406.5	584.3	175.5	164.4	34.8
2	CSBM	50	60.8	1258.6	580.6	1188.1	544.0	319.7	300.5	52.1
1	SBH	25	60.4	1511.3	313.3	1413.1	297.9	286.7	267.8	45.1
1	SBH	25	63.1	1282.7	293.6	1201.9	279.2	298.2	279.5	12.9
1	SBH	25	58.6	1223.3	256.0	1146.2	243.4	297.0	277.7	31.6
2	SBH	25	58.1	1512.6	332.0	1429.4	315.8	232.6	220.3	40.1
2	SBH	25	61.7	1726.1	330.3	1641.5	314.1	431.5	406.0	55.3
2	SBH	25	54.9	1521.0	289.1	1441.9	274.9	302.2	283.2	60.2
1	SBH	50	65.4	1244.6	593.4	1166.2	564.3	236.8	220.9	16.7
1	SBH	50	65.4	954.6	382.2	888.8	363.4	391.5	366.8	0.0
1	SBH	50	72.6	914.4	479.7	856.8	456.2	299.2	280.3	17.2
2	SBH	50	51.8	1381.8	768.8	1301.7	731.1	440.7	414.7	33.0
2	SBH	50	72.6	1235.0	526.3	1163.4	500.5	281.5	265.5	42.7
2	SBH	50	60.4	1184.3	477.9	1121.5	454.5	263.1	248.4	11.6
1	WM	25	61.7	1130.3	133.8	1055.7	123.4	149.0	138.1	23.3
1	WM	25	76.3	1454.3	272.1	1358.3	250.8	312.7	290.8	33.4
1	WM	25	60.8	1462.1	300.6	1367.1	277.2	304.4	284.3	28.2
2	WM	25	64.0	1425.6	251.5	1345.7	231.9	342.8	320.8	69.9
2	WM	25	61.7	1403.0	257.8	1320.2	237.7	250.9	234.8	38.8
2	WM	25	52.7	1490.1	251.5	1417.1	231.9	354.9	339.3	21.4
1	WM	50	63.6	1154.4	544.1	1079.4	501.7	160.4	150.6	175.9
1	WM	50	63.6	1260.1	569.1	1174.4	524.7	318.4	296.8	30.1
1	WM	50	60.4	1263.0	521.8	1183.4	481.1	305.6	284.8	260.2
2	WM	50	61.3	936.5	354.1	879.4	326.5	279.6	262.6	0.0
2	WM	50	48.1	1118.0	484.4	1059.9	446.6	389.8	367.2	16.0
2	WM	50	55.4	1064.8	396.9	1006.3	366.0	248.7	233.8	32.7

Data for digestibility trial in Year 2 (Cont).

PER	SOURCE	LEVEL	WSOM	FEDM	FEOM	HYNDF	CONDF	ORNDF	WSNDF	FENDF
1	CONTROL	0	20.4	690.9	645.3	1189.3	0.0	320.8	17.8	480.2
1	CONTROL	0	26.0	661.8	618.8	1114.1	0.0	304.5	22.5	470.5
1	CONTROL	0	29.0	675.8	633.9	1165.7	0.0	288.5	24.8	477.8
1	CONTROL	0	23.1	495.8	466.5	870.7	0.0	255.0	20.0	357.5
1	CONTROL	0	25.5	398.4	364.5	723.5	0.0	478.8	22.1	299.2
1	CONTROL	0	24.7	547.3	513.4	952.3	0.0	240.2	21.4	401.2
2	CONTROL	0	69.4	584.9	539.3	897.7	0.0	321.0	57.4	439.9
2	CONTROL	0	36.0	609.0	568.2	998.3	0.0	209.1	29.9	458.6
2	CONTROL	0	69.0	554.9	518.3	882.7	0.0	227.6	58.5	431.2
2	CONTROL	0	36.3	610.6	575.1	1046.0	0.0	207.0	31.4	454.3
2	CONTROL	0	25.5	645.8	609.0	997.1	0.0	140.1	21.2	498.6
2	CONTROL	0	260.7	536.4	499.4	883.2	0.0	280.0	218.4	408.2
1	CSBM	25	40.8	637.7	593.7	1019.1	30.9	309.8	36.0	475.8
1	CSBM	25	9.9	497.8	448.1	800.4	27.4	312.5	8.8	352.0
1	CSBM	25	15.4	416.2	380.0	614.1	25.6	320.0	13.5	293.0
2	CSBM	25	28.9	711.0	666.2	1082.0	29.2	138.6	24.7	539.0
2	CSBM	25	59.3	595.2	557.1	968.1	26.9	213.8	49.7	448.2
2	CSBM	25	50.5	617.0	559.6	960.0	27.0	171.8	42.9	455.9
1	CSBM	50	33.6	468.4	430.5	640.1	52.3	299.2	28.7	349.4
1	CSBM	50	19.9	451.5	412.2	631.1	54.8	227.5	17.3	327.8
1	CSBM	50	16.0	425.3	384.0	502.9	62.0	391.9	13.6	291.3
2	CSBM	50	55.5	618.7	576.6	876.5	63.3	183.8	45.6	440.5
2	CSBM	50	32.3	769.1	709.9	1030.2	78.0	141.3	27.4	543.7
2	CSBM	50	47.7	576.6	534.5	698.8	72.6	251.9	40.0	399.6
1	SBH	25	42.0	638.3	595.6	940.1	186.1	233.4	36.5	469.8
1	SBH	25	12.0	535.3	499.4	784.1	174.4	244.9	10.5	383.8
1	SBH	25	27.2	532.8	494.9	738.2	152.0	250.1	22.8	380.4
2	SBH	25	37.1	718.7	670.6	994.5	197.2	185.6	31.9	530.4
2	SBH	25	52.0	704.5	635.5	991.4	196.2	339.6	44.0	524.1
2	SBH	25	56.5	667.5	628.1	960.5	171.7	228.8	47.5	510.0
1	SBH	50	15.5	663.2	603.5	818.7	352.5	195.1	13.0	462.9
1	SBH	50	0.0	354.6	329.4	459.5	227.0	317.1	0.0	261.0
1	SBH	50	15.9	417.8	385.7	488.6	285.0	240.8	13.7	292.1
2	SBH	50	30.8	620.8	555.6	741.0	456.7	358.7	25.6	445.7
2	SBH	50	40.1	606.5	566.4	732.3	312.6	219.6	33.7	443.9
2	SBH	50	10.8	588.8	535.2	744.0	283.9	204.7	9.1	433.4
1	WM	25	21.5	490.6	454.3	782.7	46.3	123.7	19.1	336.6
1	WM	25	31.1	614.3	570.7	896.6	94.1	260.1	27.6	427.6
1	WM	25	26.1	619.5	570.5	915.0	104.0	249.3	22.9	450.4
2	WM	25	64.0	595.9	557.1	815.4	87.0	274.2	52.8	448.7
2	WM	25	36.5	671.5	629.8	889.5	89.2	200.0	31.4	485.5
2	WM	25	19.9	659.3	611.2	898.9	87.0	272.9	16.8	510.3
1	WM	50	162.2	563.9	500.7	669.3	188.3	131.2	141.0	387.4
1	WM	50	27.9	646.0	577.5	738.4	196.9	254.7	24.6	469.0
1	WM	50	237.8	553.1	501.6	554.3	180.5	247.2	209.2	397.6
2	WM	50	0.0	456.3	417.1	526.8	122.5	229.0	0.0	332.7
2	WM	50	14.7	518.9	489.3	576.2	167.6	301.7	11.8	370.0
2	WM	50	30.7	545.2	513.6	615.0	137.3	194.7	25.6	389.8

Intake and chemical composition of hay and concentrates by steers.

PER	AN	TREAT	HAYINT	HIDM	HIOM	HINDF	CONINT	CIDM	CIOM	CINDF
1	4	CONTROL	8.3	7.3	6.9	5.7	0.0	0.0	0.0	0.0
2	2	CONTROL	4.9	4.3	4.1	3.5	0.0	0.0	0.0	0.0
3	3	CONTROL	8.3	7.3	6.9	5.8	0.0	0.0	0.0	0.0
4	1	CONTROL	8.1	7.1	6.8	5.9	0.0	0.0	0.0	0.0
1	1	CSBM	7.5	6.6	6.2	5.1	3.8	3.3	3.1	0.5
2	3	CSBM	7.6	6.7	6.4	5.4	3.8	3.3	3.1	0.5
4	4	CSBM	7.7	6.8	6.5	5.6	4.2	3.7	3.4	0.6
1	3	SBH	7.2	6.3	6.0	4.9	4.5	3.9	3.7	2.4
2	4	SBH	7.4	6.6	6.2	5.3	4.0	3.5	3.3	2.1
3	1	SBH	7.0	6.2	5.8	4.9	4.2	3.7	3.5	2.3
1	2	WM	5.9	5.2	4.9	4.0	3.8	3.2	3.0	1.2
2	1	WM	6.7	5.9	5.7	4.8	4.8	4.2	3.8	1.6
3	4	WM	7.0	6.2	5.8	4.9	5.2	4.4	4.0	1.8
4	3	WM	8.1	7.1	6.8	5.9	4.4	3.8	3.5	1.5

Chromium concentration (% DM basis) and chemical composition of duodenal contents and feces by steers fed different concentrate sources.

PER	AN	TREAT	CRDUC	DMDUC	OMDUC	NDFDUC	CRFEC	DMFEC	OMFEC	NDFFEC
1	4	CONTROL	0.473	90.8	78.4	45.4	0.636	89.4	93.9	78.1
2	2	CONTROL	0.774	90.2	78.1	42.8	1.166	89.7	91.3	72.4
3	3	CONTROL	0.498	90.0	80.6	47.0	0.637	89.8	91.9	73.5
4	1	CONTROL	0.610	87.0	82.1	60.5	0.646	90.1	93.0	76.0
1	1	CSBM	0.440	86.7	81.7	51.0	0.578	88.8	91.1	72.2
2	3	CSBM	0.405	89.6	82.6	42.4	0.604	89.3	92.4	72.4
4	4	CSBM	0.385	89.0	82.7	42.9	0.528	89.9	93.2	74.6
1	3	SBH	0.434	89.3	81.4	46.9	0.562	89.0	91.8	73.7
2	4	SBH	0.395	89.9	79.9	46.1	0.573	89.3	93.1	74.8
3	1	SBH	0.495	87.2	79.2	46.2	0.595	89.3	89.7	68.8
1	2	WM	0.463	88.2	80.4	42.1	0.642	89.0	90.9	73.7
2	1	WM	0.437	87.7	83.3	50.8	0.543	89.3	91.2	73.2
3	4	WM	0.352	89.3	78.2	38.3	0.504	89.3	92.0	71.4
4	3	WM	0.370	89.9	83.9	48.3	0.472	89.8	92.2	75.1

In situ trial: sample weight and NDF percentage of concentrates

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
1	1	CSBM	36	2.5024	7.5049	5.0025	0.3589	53.0
1	1	CSBM	24	2.4354	7.4369	5.0015	0.8012	49.7
1	1	CSBM	18	2.4397	7.4413	5.0016	1.1452	39.2
1	1	CSBM	12	2.48	7.483	5.003	1.9309	33.7
1	1	CSBM	8	2.4538	7.4567	5.0029	2.3105	28.8
1	1	CSBM	6	2.4234	7.4283	5.0049	2.5948	27.9
1	1	CSBM	4	2.45	7.4517	5.0017	2.569	28.3
1	1	CSBM	2	2.5098	7.5132	5.0034	2.7096	28.1
1	1	CSBM	1	2.4634	7.4674	5.004	2.8229	26.9
1	1	CSBM	0.5	2.5213	7.529	5.0077	2.7047	30.2
1	1	CSBM	0	2.4724	7.4758	5.0034	3.1026	25.8
1	2	WM	36	2.4589	7.4636	5.0047	0.9417	84.1
1	2	WM	24	2.4674	7.4713	5.0039	1.1387	83.2
1	2	WM	18	2.455	7.4589	5.0039	1.3589	78.3
1	2	WM	12	2.459	7.4633	5.0043	1.3853	73.4
1	2	WM	8	2.4895	7.495	5.0055	1.8306	68.2
1	2	WM	6	2.4883	7.4923	5.004	1.906	65.8
1	2	WM	4	2.468	7.4713	5.0033	2.4861	59.2
1	2	WM	2	2.4403	7.4443	5.004	2.6836	59.4
1	2	WM	1	2.4904	7.4954	5.005	2.8557	57.0
1	2	WM	0.5	2.5171	7.5184	5.0013	2.8686	55.4
1	2	WM	0	2.421	7.4222	5.0012	3.0728	53.0
1	3	SBH	36	2.4549	7.4576	5.0027	0.4808	64.6
1	3	SBH	24	2.4609	7.4615	5.0006	1.5655	77.3
1	3	SBH	18	2.4414	7.4472	5.0058	2.4449	78.7
1	3	SBH	12	2.4343	7.4398	5.0055	1.8824	70.4
1	3	SBH	8	2.4814	7.4876	5.0062	2.9596	72.4
1	3	SBH	6	2.4613	7.4654	5.0041	2.8598	70.0
1	3	SBH	4	2.4703	7.4757	5.0054	3.3877	71.3
1	3	SBH	2	2.4662	7.4717	5.0055	3.5925	71.7
1	3	SBH	1	2.4456	7.447	5.0014	3.6415	70.8
1	3	SBH	0.5	2.5043	7.5099	5.0056	3.7008	70.1
1	3	SBH	0	2.5441	7.5448	5.0007	3.7424	69.6
2	1	WM	36	2.4607	7.4649	5.0042	0.9437	84.7
2	1	WM	24	2.5153	7.5185	5.0032	1.0935	83.4
2	1	WM	18	2.4492	7.4524	5.0032	1.1382	84.0
2	1	WM	12	2.4454	7.4498	5.0044	1.2671	81.3
2	1	WM	8	2.4569	7.4587	5.0018	1.8029	71.2
2	1	WM	6	2.4578	7.4623	5.0045	2.211	63.7
2	1	WM	4	2.4313	7.4345	5.0032	2.4537	60.9
2	1	WM	2	2.4894	7.4922	5.0028	2.6223	62.9
2	1	WM	1	2.4687	7.4734	5.0047	2.6992	62.2
2	1	WM	0.5	2.4484	7.4511	5.0027	2.8585	59.4
2	1	WM	0	2.4589	7.4622	5.0033	2.9308	58.0

In situ trial: sample weight and NDF percentage of concentrates (Cont.).

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
2	3	CSBM	36	2.5131	7.5169	5.0038	0.3453	64.9
2	3	CSBM	24	2.4603	7.4644	5.0041	0.7533	48.6
2	3	CSBM	18	2.4509	7.4527	5.0018	1.0304	43.4
2	3	CSBM	12	2.4657	7.466	5.0003	1.858	32.6
2	3	CSBM	8	2.4682	7.4749	5.0067	2.1627	29.0
2	3	CSBM	6	2.5231	7.5229	4.9998	2.1573	31.7
2	3	CSBM	4	2.4918	7.4944	5.0026	2.4621	27.1
2	3	CSBM	2	2.4253	7.4298	5.0045	2.4946	25.9
2	3	CSBM	1	2.4594	7.4632	5.0038	2.638	27.2
2	3	CSBM	0.5	2.4642	7.4666	5.0024	2.7243	26.0
2	3	CSBM	0	2.4691	7.4717	5.0026	2.7235	23.6
2	4	SBH	36	2.4449	7.4469	5.002	0.5697	81.1
2	4	SBH	24	2.4283	7.4345	5.0062	2.0221	85.2
2	4	SBH	18	2.4341	7.4392	5.0051	2.6183	82.0
2	4	SBH	12	2.4279	7.4325	5.0046	3.1611	77.0
2	4	SBH	8	2.441	7.4446	5.0036	3.4392	74.0
2	4	SBH	6	2.4691	7.4757	5.0066	3.5348	73.7
2	4	SBH	4	2.4526	7.4593	5.0067	3.6077	73.2
2	4	SBH	2	2.4196	7.4216	5.002	3.673	72.5
2	4	SBH	1	2.435	7.4419	5.0069	3.7476	72.0
2	4	SBH	0.5	2.4692	7.471	5.0018	3.7682	71.9
2	4	SBH	0	2.4408	7.443	5.0022	3.8428	78.9
3	1	SBH	36	2.5151	7.5161	5.001	0.8106	79.7
3	1	SBH	24	2.5478	7.5488	5.001	1.4987	83.3
3	1	SBH	18	2.5245	7.5251	5.0006	2.1098	84.0
3	1	SBH	12	2.4955	7.4957	5.0002	2.3373	82.3
3	1	SBH	8	2.5225	7.5241	5.0016	2.7523	78.8
3	1	SBH	6	2.5043	7.5052	5.0009	3.4059	73.6
3	1	SBH	4	2.4633	7.4642	5.0009	3.4937	73.0
3	1	SBH	2	2.509	7.511	5.002	3.6979	71.6
3	1	SBH	1	2.4797	7.4824	5.0027	3.7477	70.8
3	1	SBH	0.5	2.4314	7.4324	5.001	3.8045	71.3
3	1	SBH	0	2.459	7.4606	5.0016	3.8494	70.7
3	4	WM	36	2.4774	7.4806	5.0032	1.0529	84.2
3	4	WM	24	2.4957	7.4974	5.0017	1.1412	84.6
3	4	WM	18	2.4728	7.474	5.0012	1.1806	84.3
3	4	WM	12	2.4682	7.4707	5.0025	1.2091	84.0
3	4	WM	8	2.5042	7.506	5.0018	1.7252	68.7
3	4	WM	6	2.5193	7.5198	5.0005	2.1811	63.0
3	4	WM	4	2.4763	7.4791	5.0028	2.4962	59.1
3	4	WM	2	2.4518	7.4534	5.0016	2.7598	57.7
3	4	WM	1	2.4637	7.4647	5.001	2.8462	57.3
3	4	WM	0.5	2.4771	7.48	5.0029	3.0348	56.0
3	4	WM	0	2.4257	7.4259	5.0002	3.3332	51.0

In situ trial: sample weight and NDF percentage of concentrates (Cont.).

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
4	3	WM	36	2.4794	7.4811	5.0017	0.9299	84.6
4	3	WM	24	2.5046	7.5047	5.0001	1.0903	83.8
4	3	WM	18	2.4774	7.4791	5.0017	1.2996	81.1
4	3	WM	12	2.4833	7.4856	5.0023	1.3733	80.6
4	3	WM	8	2.5097	7.5122	5.0025	1.5565	73.8
4	3	WM	6	2.4796	7.4844	5.0048	1.97	66.7
4	3	WM	4	2.5065	7.5063	4.9998	2.2157	64.7
4	3	WM	2	2.5014	7.5052	5.0038	2.4926	59.2
4	3	WM	1	2.4645	7.4697	5.0052	2.6556	58.1
4	3	WM	0.5	2.471	7.4737	5.0027	2.7887	55.9
4	3	WM	0	2.4388	7.4425	5.0037	3.1201	55.8
4	4	CSBM	36	2.4588	7.4607	5.0019	0.3052	61.9
4	4	CSBM	24	2.5056	7.5109	5.0053	1.311	38.3
4	4	CSBM	18	2.4793	7.4802	5.0009	1.7482	31.4
4	4	CSBM	12	2.5024	7.5034	5.001	2.0961	27.8
4	4	CSBM	8	2.49	7.493	5.003	2.2523	27.3
4	4	CSBM	6	2.5323	7.5383	5.006	2.5125	25.6
4	4	CSBM	4	2.5164	7.5165	5.0001	2.5227	25.4
4	4	CSBM	2	2.5333	7.5332	4.9999	2.5757	25.3
4	4	CSBM	1	2.5197	7.5228	5.0031	2.5009	27.3
4	4	CSBM	0.5	2.5769	7.5768	4.9999	2.6157	24.1
4	4	CSBM	0	2.5161	7.5195	5.0034	2.9104	23.3

Parameters and secondary variable estimates for DM in concentrates using nylon bags.

PER	AN	TREAT	SOLFRACP	SLOWDFRP	UNDIGFP	LAG	KD	EXTDIG
1	1	CSBM	37.9	54.6	7.4	0.0	0.056	73.5
2	3	CSBM	45.6	47.4	7.0	1.7	0.061	71.8
4	4	CSBM	41.8	52.0	6.2	0.0	0.036	54.6
1	3	SBH	25.2	65.1	9.7	0.3	0.043	57.8
2	4	SBH	23.2	65.2	11.6	3.2	0.033	46.5
3	1	SBH	23.0	60.5	16.5	1.7	0.059	60.4
1	2	WM	38.6	42.3	19.1	0.0	0.109	62.4
2	1	WM	41.4	39.3	19.3	0.4	0.111	62.2
3	4	WM	33.3	45.4	21.3	0.0	0.145	65.3
4	3	WM	37.6	43.4	19.0	0.0	0.139	64.6

Parameters and secondary variable estimates for NDF in concentrates using nylon bags.

PER	AN	TREAT	SOLFRACP	SLOWDFRP	UNDIGFP	LAG	KD	EXTDIG
1	1	CSBM	3.1	73.2	23.6	1.7	0.042	48.9
2	3	CSBM	26.3	47.5	26.2	0.5	0.039	42.0
4	4	CSBM	19.7	57.7	22.6	0.0	0.019	25.3
1	3	SBH	21.9	68.7	9.4	0.4	0.037	46.9
2	4	SBH	9.0	76.9	14.1	0.0	0.027	42.2
3	1	SBH	19.4	61.1	19.5	2.8	0.049	53.3
1	2	WM	23.2	38.8	38.0	1.2	0.089	41.0
2	1	WM	24.2	39.3	36.5	1.7	0.108	45.7
3	4	WM	23.0	36.4	40.6	0.7	0.120	42.5
4	3	WM	15.3	45.6	39.1	0.0	0.101	46.8

In situ trial: sample weight and NDF percentage of hay.

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
1	1	HAYCS	96	2.5158	7.5163	5.0005	1.7363	84.8
1	1	HAYCS	72	2.4706	7.4713	5.0007	1.8402	85.7
1	1	HAYCS	48	2.4429	7.4452	5.0023	1.9202	85.5
1	1	HAYCS	24	2.4292	7.4304	5.0012	2.4189	84.9
1	1	HAYCS	18	2.4262	7.4290	5.0028	2.6371	85.5
1	1	HAYCS	12	2.4301	7.4318	5.0017	3.0958	86.0
1	1	HAYCS	8	2.4260	7.4271	5.0011	3.3407	86.1
1	1	HAYCS	6	2.4509	7.4542	5.0033	3.3816	85.9
1	1	HAYCS	4	2.4972	7.4997	5.0025	3.6255	86.4
1	1	HAYCS	2	2.4621	7.4623	5.0002	3.6811	88.6
1	1	HAYCS	0	2.4672	7.4684	5.0012	3.7108	89.5
1	2	HAYWM	96	2.4686	7.4705	5.0019	1.7765	86.2
1	2	HAYWM	72	2.4283	7.4318	5.0035	1.9066	86.0
1	2	HAYWM	48	2.4541	7.4554	5.0013	1.9757	86.1
1	2	HAYWM	24	2.4921	7.4954	5.0033	2.4400	86.7
1	2	HAYWM	18	2.4520	7.4523	5.0003	2.5921	86.2
1	2	HAYWM	12	2.4675	7.4689	5.0014	3.0837	85.8
1	2	HAYWM	8	2.4468	7.4515	5.0047	3.3567	85.6
1	2	HAYWM	6	2.4473	7.4502	5.0029	3.5464	85.9
1	2	HAYWM	4	2.4204	7.4292	5.0088	3.6356	88.0
1	2	HAYWM	2	2.4161	7.4190	5.0029	3.6522	88.8
1	2	HAYWM	0	2.4714	7.4744	5.0030	3.7133	88.8
1	3	HAYSBH	96	2.4570	7.4586	5.0016	1.7492	84.4
1	3	HAYSBH	72	2.4891	7.4905	5.0014	1.8422	85.2
1	3	HAYSBH	48	2.4963	7.4963	5.0000	1.9896	86.8
1	3	HAYSBH	24	2.4629	7.4658	5.0029	2.3286	85.0
1	3	HAYSBH	18	2.4493	7.4500	5.0007	2.5144	84.7
1	3	HAYSBH	12	2.4454	7.4453	4.9999	2.8925	83.8
1	3	HAYSBH	8	2.5057	7.5094	5.0037	3.2596	84.8
1	3	HAYSBH	6	2.4384	7.4391	5.0007	3.4515	85.6
1	3	HAYSBH	4	2.4470	7.4476	5.0006	3.5586	86.4
1	3	HAYSBH	2	2.4547	7.4554	5.0007	3.6516	89.0
1	3	HAYSBH	0	2.4641	7.4655	5.0014	3.7137	89.0
1	4	HAYCON	96	2.4697	7.4706	5.0009	1.7797	86.3
1	4	HAYCON	72	2.3953	7.3959	5.0006	1.8604	86.8
1	4	HAYCON	48	2.5114	7.5133	5.0019	2.0247	86.2
1	4	HAYCON	24	2.4761	7.4773	5.0012	2.9696	86.2
1	4	HAYCON	18	2.4379	7.4379	5.0000	3.3962	89.5
1	4	HAYCON	12	2.4695	7.4733	5.0038	3.4897	89.5
1	4	HAYCON	8	2.4482	7.4485	5.0003	3.5523	90.2
1	4	HAYCON	6	2.4227	7.4287	5.0060	3.5523	89.4
1	4	HAYCON	4	2.4604	7.4620	5.0016	3.6144	89.6
1	4	HAYCON	2	2.4908	7.4911	5.0003	3.6619	89.5
1	4	HAYCON	0	2.4713	7.4739	5.0026	3.7484	89.6

In situ trial: sample weight and NDF percentage of hay (Cont).

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
2	1	HAYWM	96	2.4694	7.4706	5.0012	2.0318	87.4
2	1	HAYWM	72	2.4387	7.4404	5.0017	2.1558	86.6
2	1	HAYWM	48	2.4636	7.4656	5.0020	2.2910	86.3
2	1	HAYWM	24	2.5005	7.5051	5.0046	2.9638	88.2
2	1	HAYWM	18	2.4947	7.4973	5.0026	3.2210	88.6
2	1	HAYWM	12	2.3991	7.4005	5.0014	3.3699	87.9
2	1	HAYWM	8	2.4692	7.4729	5.0037	3.6967	88.4
2	1	HAYWM	6	2.5107	7.5150	5.0043	3.8381	88.1
2	1	HAYWM	4	2.4549	7.4591	5.0042	3.8785	88.7
2	1	HAYWM	2	2.4649	7.4692	5.0043	3.9592	88.9
2	1	HAYWM	0	2.4458	7.4477	5.0019	4.0139	88.8
2	2	HAYCON	96	2.4631	7.4692	5.0061	2.0144	83.0
2	2	HAYCON	72	2.4657	7.4686	5.0029	2.1338	84.7
2	2	HAYCON	48	2.4438	7.4456	5.0018	2.2273	85.8
2	2	HAYCON	24	2.4867	7.4899	5.0032	2.8250	86.8
2	2	HAYCON	18	2.4732	7.4747	5.0015	3.0188	86.8
2	2	HAYCON	12	2.4391	7.4403	5.0012	3.5589	87.5
2	2	HAYCON	8	2.4876	7.4911	5.0035	3.7442	87.7
2	2	HAYCON	6	2.4769	7.4804	5.0035	3.8154	88.2
2	2	HAYCON	4	2.4506	7.4536	5.0030	3.9161	88.2
2	2	HAYCON	2	2.4461	7.4493	5.0032	3.9618	88.0
2	2	HAYCON	0	2.4467	7.4517	5.0050	4.0328	89.0
2	3	HAYCS	96	2.4797	7.4850	5.0053	1.9343	79.6
2	3	HAYCS	72	2.4630	7.4672	5.0042	2.0832	86.0
2	3	HAYCS	48	2.4321	7.4361	5.0040	2.3231	86.5
2	3	HAYCS	24	2.4533	7.4546	5.0013	2.8406	85.5
2	3	HAYCS	18	2.4491	7.4499	5.0008	3.1277	85.3
2	3	HAYCS	12	2.4525	7.4564	5.0039	3.5772	87.9
2	3	HAYCS	8	2.4674	7.4684	5.0010	3.7566	88.1
2	3	HAYCS	6	2.4892	7.4935	5.0043	3.8189	88.5
2	3	HAYCS	4	2.4859	7.4880	5.0021	3.8873	88.1
2	3	HAYCS	2	2.4468	7.4472	5.0004	3.9504	88.9
2	3	HAYCS	0	2.4440	7.4452	5.0012	4.0078	89.1
2	4	HAYSBH	96	2.4562	7.4573	5.0011	1.9303	84.8
2	4	HAYSBH	72	2.4688	7.4696	5.0008	2.0718	85.6
2	4	HAYSBH	48	2.4611	7.4642	5.0031	2.3017	85.5
2	4	HAYSBH	24	2.4439	7.4450	5.0011	2.8852	87.2
2	4	HAYSBH	18	2.4764	7.4783	5.0019	3.0449	87.3
2	4	HAYSBH	12	2.4912	7.4928	5.0016	3.3003	87.4
2	4	HAYSBH	8	2.4904	7.4960	5.0056	3.6914	88.4
2	4	HAYSBH	6	2.4448	7.4474	5.0026	3.7495	88.7
2	4	HAYSBH	4	2.4834	7.4847	5.0013	3.8662	89.3
2	4	HAYSBH	2	2.4648	7.4647	4.9999	3.9509	89.3
2	4	HAYSBH	0	2.4595	7.4643	5.0048	3.9936	89.5

In situ trial: sample weight and NDF percentage of hay (Cont).

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
3	1	HAYSBH	96	2.4638	7.4648	5.0010	1.7250	84.3
3	1	HAYSBH	72	2.4984	7.4992	5.0008	1.8581	84.1
3	1	HAYSBH	48	2.4567	7.4584	5.0017	2.0676	83.9
3	1	HAYSBH	24	2.4853	7.4877	5.0024	2.7842	84.5
3	1	HAYSBH	18	2.5286	7.5298	5.0012	3.1618	86.3
3	1	HAYSBH	12	2.4504	7.4525	5.0021	3.5027	86.8
3	1	HAYSBH	8	2.5856	7.5858	5.0002	3.7178	87.3
3	1	HAYSBH	6	2.4985	7.5005	5.0020	3.7907	87.9
3	1	HAYSBH	4	2.4939	7.4942	5.0003	3.8476	87.9
3	1	HAYSBH	2	2.4708	7.4749	5.0041	3.9250	88.3
3	1	HAYSBH	0	2.4946	7.4960	5.0014	3.9732	87.8
3	3	HAYCON	96	2.4743	7.4773	5.0030	1.6630	83.6
3	3	HAYCON	72	2.5387	7.5412	5.0025	1.7802	85.4
3	3	HAYCON	48	2.5748	7.5775	5.0027	1.9940	85.0
3	3	HAYCON	24	2.4925	7.4961	5.0036	2.4450	84.8
3	3	HAYCON	18	2.4920	7.4930	5.0010	3.0440	85.6
3	3	HAYCON	12	2.4829	7.4838	5.0009	3.4828	86.7
3	3	HAYCON	8	2.5663	7.5682	5.0019	3.6472	86.5
3	3	HAYCON	6	2.4982	7.5002	5.0020	3.7757	87.3
3	3	HAYCON	4	2.4802	7.4807	5.0005	3.8014	86.9
3	3	HAYCON	2	2.4778	7.4778	5.0000	3.8922	87.4
3	3	HAYCON	0	2.4307	7.4318	5.0011	3.9577	86.8
3	4	HAYWM	96	2.5075	7.5091	5.0016	1.8604	83.3
3	4	HAYWM	72	2.4352	7.4390	5.0038	1.8746	83.0
3	4	HAYWM	48	2.4477	7.4490	5.0013	2.2320	85.3
3	4	HAYWM	24	2.5363	7.5388	5.0025	2.6257	85.9
3	4	HAYWM	18	2.5083	7.5099	5.0016	2.9184	86.5
3	4	HAYWM	12	2.5150	7.5176	5.0026	3.3602	86.9
3	4	HAYWM	8	2.4930	7.4968	5.0038	3.7302	87.1
3	4	HAYWM	6	2.4594	7.4628	5.0034	3.7452	87.3
3	4	HAYWM	4	2.4865	7.4884	5.0019	3.8634	87.4
3	4	HAYWM	2	2.4637	7.4642	5.0005	3.8962	87.8
3	4	HAYWM	0	2.4732	7.4752	5.0020	3.9596	87.9
4	1	HAYCON	96	2.4686	7.4692	5.0006	1.9468	86.1
4	1	HAYCON	72	2.4450	7.4451	5.0001	2.1292	86.5
4	1	HAYCON	48	2.5425	7.5440	5.0015	2.2811	86.7
4	1	HAYCON	24	2.5151	7.5163	5.0012	2.8525	87.6
4	1	HAYCON	18	2.4919	7.4943	5.0024	3.2019	87.8
4	1	HAYCON	12	2.5091	7.5108	5.0017	3.4986	88.8
4	1	HAYCON	8	2.5067	7.5090	5.0023	3.7596	90.0
4	1	HAYCON	6	2.5100	7.5126	5.0026	3.8625	89.7
4	1	HAYCON	4	2.5453	7.5492	5.0039	3.8946	89.7
4	1	HAYCON	2	2.4384	7.4396	5.0012	3.9596	89.5
4	1	HAYCON	0	2.4452	7.4467	5.0015	4.0164	89.9

In situ trial: sample weight and NDF percentage of hay (Cont).

PER	AN	TREAT	TIME	BAGWT	BAG+SWT	SMPLWT	DRYWT48	NDF%DM
4	3	HAYWM	96	2.5383	7.5394	5.0011	2.0223	84.2
4	3	HAYWM	72	2.5112	7.5141	5.0029	2.1135	85.0
4	3	HAYWM	48	2.4728	7.4754	5.0026	2.2839	85.8
4	3	HAYWM	24	2.4347	7.4351	5.0004	2.6980	86.2
4	3	HAYWM	18	2.4592	7.4610	5.0018	3.0235	86.5
4	3	HAYWM	12	2.4948	7.4959	5.0011	3.3110	87.2
4	3	HAYWM	8	2.4699	7.4698	4.9999	3.6784	88.2
4	3	HAYWM	6	2.5100	7.5108	5.0008	3.8328	89.4
4	3	HAYWM	4	2.4973	7.4980	5.0007	3.9002	88.7
4	3	HAYWM	2	2.4694	7.4706	5.0012	3.9613	89.8
4	3	HAYWM	0	2.4940	7.4955	5.0015	4.0190	90.0
4	4	HAYCS	96	2.4982	7.4990	5.0008	2.1965	85.9
4	4	HAYCS	72	2.4796	7.4805	5.0009	2.3585	86.8
4	4	HAYCS	48	2.4724	7.4744	5.0020	2.7547	88.3
4	4	HAYCS	24	2.4925	7.4942	5.0017	3.4344	88.8
4	4	HAYCS	18	2.4531	7.4555	5.0024	3.4813	88.1
4	4	HAYCS	12	2.4492	7.4510	5.0018	3.5653	88.2
4	4	HAYCS	8	2.4754	7.4770	5.0016	3.7412	89.1
4	4	HAYCS	6	2.4613	7.4646	5.0033	3.8819	88.9
4	4	HAYCS	4	2.4486	7.4497	5.0011	3.9395	89.9
4	4	HAYCS	2	2.4687	7.4697	5.0010	3.9790	90.3
4	4	HAYCS	0	2.5012	7.5053	5.0041	4.0226	89.5

Parameters and secondary variable estimates for DM in hay using nylon bags.

PER	AN	TREAT	SOLFRACP	SLOWDFRP	UNDIGFP	LAG	KD	EXTDIG
1	4	HAYCON	25.1	39.2	35.7	10.8	0.043	50.1
2	2	HAYCON	20.2	41.2	38.6	2.6	0.038	48.1
3	3	HAYCON	20.8	41.5	37.7	4.6	0.048	52.1
4	1	HAYCON	19.6	36.4	44.0	2.5	0.025	41.2
1	1	HAYCS	25.8	39.1	35.1	3.2	0.050	49.9
2	3	HAYCS	19.4	40.2	40.4	4.5	0.047	46.9
4	4	HAYCS	19.6	39.8	40.6	3.4	0.048	47.2
1	3	HAYSBH	25.8	39.0	35.2	3.1	0.058	50.0
2	4	HAYSBH	19.9	41.3	38.8	3.7	0.037	47.8
3	1	HAYSBH	20.6	44.7	34.7	3.9	0.036	53.0
1	2	HAYWM	25.8	38.5	35.7	3.9	0.053	48.4
2	1	HAYWM	19.8	39.4	40.8	3.1	0.038	46.1
3	4	HAYWM	20.9	45.7	33.4	5.1	0.045	54.8
4	3	HAYWM	19.5	37.5	43.0	3.9	0.035	42.4

Parameters and secondary variable estimates for NDF in hay using nylon bags.

PER	AN	TREAT	SOLFRACP	SLOWDFRP	UNDIGFP	LAG	KD	EXTDIG
1	4	HAYCON	22.8	41.8	35.4	10.8	0.045	51.7
2	2	HAYCON	18.0	44.4	37.6	2.4	0.039	49.7
3	3	HAYCON	20.0	44.0	36.0	3.6	0.045	54.8
4	1	HAYCON	15.7	40.0	44.3	2.3	0.025	43.0
1	1	HAYCS	24.5	41.6	33.9	1.6	0.049	52.0
2	3	HAYCS	18.3	43.5	38.2	3.3	0.042	49.5
4	4	HAYCS	16.0	44.3	39.7	3.0	0.049	50.2
1	3	HAYSBH	24.5	41.5	34.0	1.7	0.058	52.1
2	4	HAYSBH	18.3	46.3	35.4	3.0	0.034	49.6
3	1	HAYSBH	20.0	46.4	33.6	4.9	0.041	55.0
1	2	HAYWM	25.1	39.9	35.0	3.1	0.054	50.0
2	1	HAYWM	18.7	40.6	40.7	3.0	0.039	47.4
3	4	HAYWM	20.6	47.1	32.3	5.2	0.046	55.5
4	3	HAYWM	16.4	40.3	43.3	2.9	0.038	44.0

Dysprosium concentration (ppm) by steers fed different concentrate sources.

PER	AN	TREAT	TIME	DYPPM
1	1	CSBM	4	0.21
1	1	CSBM	8	1.62
1	1	CSBM	12	3.37
1	1	CSBM	16	3.61
1	1	CSBM	20	4.36
1	1	CSBM	24	4.01
1	1	CSBM	28	3.93
1	1	CSBM	32	2.53
1	1	CSBM	36	1.97
1	1	CSBM	42	1.92
1	1	CSBM	48	1.40
1	1	CSBM	54	1.19
1	1	CSBM	60	0.82
1	1	CSBM	72	0.45
1	2	WM	4	0.04
1	2	WM	8	0.46
1	2	WM	12	2.07
1	2	WM	16	3.17
1	2	WM	20	4.23
1	2	WM	24	4.77
1	2	WM	28	3.42
1	2	WM	32	2.97
1	2	WM	36	2.33
1	2	WM	42	1.44
1	2	WM	48	1.43
1	2	WM	54	1.10
1	2	WM	60	0.71
1	2	WM	72	0.50
1	3	SBH	4	0.01
1	3	SBH	8	0.81
1	3	SBH	12	2.94
1	3	SBH	16	3.73
1	3	SBH	20	3.79
1	3	SBH	24	3.49
1	3	SBH	28	3.28
1	3	SBH	32	2.65
1	3	SBH	36	1.85
1	3	SBH	42	1.13
1	3	SBH	48	0.65
1	3	SBH	54	0.47
1	3	SBH	60	0.06
1	3	SBH	72	0.00
1	4	CONTROL	4	0.00
1	4	CONTROL	8	0.53
1	4	CONTROL	12	0.55
1	4	CONTROL	16	1.47
1	4	CONTROL	20	3.82
1	4	CONTROL	24	3.63
1	4	CONTROL	28	3.29
1	4	CONTROL	32	3.23
1	4	CONTROL	36	3.10
1	4	CONTROL	42	2.10
1	4	CONTROL	48	1.94
1	4	CONTROL	54	1.75
1	4	CONTROL	60	1.23
1	4	CONTROL	72	0.70
2	1	WM	4	0.09
2	1	WM	8	1.06
2	1	WM	12	2.42
2	1	WM	16	3.54
2	1	WM	20	3.69
2	1	WM	24	3.58
2	1	WM	28	3.25
2	1	WM	32	2.82
2	1	WM	36	2.06
2	1	WM	42	1.87
2	1	WM	48	1.48
2	1	WM	54	0.82
2	1	WM	60	0.69
2	1	WM	72	0.48
2	2	CONTROL	4	0.00
2	2	CONTROL	8	0.04
2	2	CONTROL	12	0.07
2	2	CONTROL	16	0.95
2	2	CONTROL	20	2.07
2	2	CONTROL	24	3.16
2	2	CONTROL	28	4.55
2	2	CONTROL	32	4.73
2	2	CONTROL	36	4.47
2	2	CONTROL	42	4.00
2	2	CONTROL	48	3.57
2	2	CONTROL	54	2.84
2	2	CONTROL	60	2.82
2	2	CONTROL	72	1.84

Dysprosium concentration (ppm) by steers fed different concentrate sources (Cont.).

PER	AN	TREAT	TIME	DYPPM	PER	AN	TREAT	TIME	DYPPM
2	3	CSBM	4	0.00	3	3	CONTROL	4	0.00
2	3	CSBM	8	1.12	3	3	CONTROL	8	0.45
2	3	CSBM	12	2.87	3	3	CONTROL	12	1.89
2	3	CSBM	16	4.58	3	3	CONTROL	16	4.07
2	3	CSBM	20	3.96	3	3	CONTROL	20	4.64
2	3	CSBM	24	3.58	3	3	CONTROL	24	4.31
2	3	CSBM	28	3.45	3	3	CONTROL	28	3.70
2	3	CSBM	32	2.66	3	3	CONTROL	32	3.24
2	3	CSBM	36	2.27	3	3	CONTROL	36	2.55
2	3	CSBM	42	1.76	3	3	CONTROL	42	2.01
2	3	CSBM	48	1.53	3	3	CONTROL	48	1.72
2	3	CSBM	54	1.29	3	3	CONTROL	54	1.20
2	3	CSBM	60	1.04	3	3	CONTROL	60	0.78
2	3	CSBM	72	0.77	3	3	CONTROL	72	0.37
2	4	SBH	4	0.30	3	4	WM	4	0.00
2	4	SBH	8	0.53	3	4	WM	8	0.21
2	4	SBH	12	1.70	3	4	WM	12	1.24
2	4	SBH	16	3.70	3	4	WM	16	3.10
2	4	SBH	20	4.02	3	4	WM	20	3.02
2	4	SBH	24	3.75	3	4	WM	24	2.91
2	4	SBH	28	3.49	3	4	WM	28	2.61
2	4	SBH	32	3.20	3	4	WM	32	1.64
2	4	SBH	36	2.40	3	4	WM	36	1.54
2	4	SBH	42	1.80	3	4	WM	42	1.41
2	4	SBH	48	1.75	3	4	WM	48	1.35
2	4	SBH	54	1.39	3	4	WM	54	1.10
2	4	SBH	60	0.97	3	4	WM	60	0.64
2	4	SBH	72	0.89	3	4	WM	72	0.63
3	1	SBH	4	0.34	4	1	CONTROL	4	0.14
3	1	SBH	8	0.94	4	1	CONTROL	8	0.52
3	1	SBH	12	3.50	4	1	CONTROL	12	1.49
3	1	SBH	16	4.38	4	1	CONTROL	16	1.88
3	1	SBH	20	4.62	4	1	CONTROL	20	3.49
3	1	SBH	24	4.38	4	1	CONTROL	24	5.01
3	1	SBH	28	3.08	4	1	CONTROL	28	5.07
3	1	SBH	32	2.93	4	1	CONTROL	32	5.61
3	1	SBH	36	1.94	4	1	CONTROL	36	4.49
3	1	SBH	42	1.62	4	1	CONTROL	42	3.93
3	1	SBH	48	1.53	4	1	CONTROL	48	3.82
3	1	SBH	54	0.85	4	1	CONTROL	54	2.71
3	1	SBH	60	0.55	4	1	CONTROL	60	2.58
3	1	SBH	72	0.33	4	1	CONTROL	72	1.82

Dysprosium concentration (ppm) by steers fed different concentrate sources (Cont.).

PER	AN	TREAT	TIME	DYPPM
4	3	WM	4	0.00
4	3	WM	8	0.57
4	3	WM	12	2.06
4	3	WM	16	3.27
4	3	WM	20	4.27
4	3	WM	24	3.55
4	3	WM	28	3.36
4	3	WM	32	3.31
4	3	WM	36	2.98
4	3	WM	42	1.87
4	3	WM	48	1.86
4	3	WM	54	1.46
4	3	WM	60	1.03
4	3	WM	72	0.62
4	4	CSBM	4	0.00
4	4	CSBM	8	0.21
4	4	CSBM	12	0.85
4	4	CSBM	16	2.17
4	4	CSBM	20	3.91
4	4	CSBM	24	3.91
4	4	CSBM	28	3.49
4	4	CSBM	32	3.33
4	4	CSBM	36	2.51
4	4	CSBM	42	2.08
4	4	CSBM	48	2.06
4	4	CSBM	54	1.61
4	4	CSBM	60	1.08
4	4	CSBM	72	0.72

Parameters and secondary variable estimates for small particles (Dy).

PER	AN	TREAT	CZERO	KPSLOW	TDELAY	DOSE	FASTMRT	SLOWMRT
1	4	CONTROL	508.6	0.0294	12.8	416.4	4.4	34.0
2	2	CONTROL	806.0	0.0297	9.3	370.9	15.1	33.7
3	3	CONTROL	789.2	0.0478	5.3	370.9	9.4	20.9
4	1	CONTROL	947.9	0.0351	3.1	556.9	18.5	28.5
1	1	CSBM	827.5	0.0498	0.0	416.4	12.8	20.1
2	3	CSBM	653.6	0.0376	3.9	370.9	7.8	26.6
4	4	CSBM	601.8	0.0363	7.7	556.9	9.1	27.5
1	3	SBH	1001.6	0.0840	1.2	416.4	14.0	11.9
2	4	SBH	638.3	0.0374	5.0	370.9	9.1	26.7
3	1	SBH	869.3	0.0536	3.4	370.9	9.3	18.7
1	2	WM	851.6	0.0586	3.9	416.4	12.0	17.1
2	1	WM	734.0	0.0480	0.9	370.9	12.9	20.8
3	4	WM	436.0	0.0353	8.6	370.9	4.7	28.3
4	3	WM	658.2	0.0378	3.2	556.9	11.3	26.5

PER	AN	TREAT	TRMRT	DUODDMO	KPFASTC	FILLUDMS	FILLUDMF	TOTALFIL
1	4	CONTROL	51.2	0.578	0.3695	0.82	0.07	0.88
2	2	CONTROL	58.1	0.328	0.1084	0.46	0.13	0.59
3	3	CONTROL	35.6	0.539	0.1735	0.47	0.13	0.60
4	1	CONTROL	50.0	0.495	0.0886	0.59	0.23	0.82
1	1	CSBM	32.9	0.601	0.1276	0.50	0.20	0.70
2	3	CSBM	38.3	0.512	0.2103	0.57	0.10	0.67
4	4	CSBM	44.4	0.806	0.1791	0.93	0.19	1.11
1	3	SBH	27.2	0.838	0.1163	0.42	0.30	0.72
2	4	SBH	40.9	0.522	0.1790	0.58	0.12	0.70
3	1	SBH	31.4	0.549	0.1753	0.43	0.13	0.56
1	2	WM	33.0	0.688	0.1363	0.49	0.21	0.70
2	1	WM	34.6	0.582	0.1267	0.51	0.19	0.70
3	4	WM	41.6	0.721	0.3470	0.85	0.09	0.94
4	3	WM	41.0	0.768	0.1446	0.85	0.22	1.07

Ytterbium concentration (ppm) by steers fed different concentrate sources.

PER	AN	TREAT	TIME	YBPPM
1	1	CSBM	4	0.00
1	1	CSBM	8	0.09
1	1	CSBM	12	0.33
1	1	CSBM	16	0.36
1	1	CSBM	20	0.50
1	1	CSBM	24	0.64
1	1	CSBM	28	0.72
1	1	CSBM	32	0.63
1	1	CSBM	36	0.55
1	1	CSBM	42	0.56
1	1	CSBM	48	0.53
1	1	CSBM	54	0.32
1	1	CSBM	60	0.27
1	1	CSBM	72	0.15
1	2	WM	4	0.00
1	2	WM	8	0.00
1	2	WM	12	0.08
1	2	WM	16	0.20
1	2	WM	20	0.37
1	2	WM	24	0.59
1	2	WM	28	0.65
1	2	WM	32	0.89
1	2	WM	36	0.74
1	2	WM	42	0.59
1	2	WM	48	0.59
1	2	WM	54	0.53
1	2	WM	60	0.40
1	2	WM	72	0.30
1	3	SBH	4	0.00
1	3	SBH	8	0.03
1	3	SBH	12	0.28
1	3	SBH	16	0.47
1	3	SBH	20	0.59
1	3	SBH	24	0.77
1	3	SBH	28	0.76
1	3	SBH	32	0.65
1	3	SBH	36	0.70
1	3	SBH	42	0.38
1	3	SBH	48	0.40
1	3	SBH	54	0.34
1	3	SBH	60	0.15
1	3	SBH	72	0.07
1	4	CONTROL	4	0.00
1	4	CONTROL	8	0.00
1	4	CONTROL	12	0.00
1	4	CONTROL	16	0.14
1	4	CONTROL	20	0.61
1	4	CONTROL	24	0.63
1	4	CONTROL	28	0.64
1	4	CONTROL	32	0.65
1	4	CONTROL	36	0.77
1	4	CONTROL	42	0.84
1	4	CONTROL	48	0.72
1	4	CONTROL	54	0.61
1	4	CONTROL	60	0.53
1	4	CONTROL	72	0.34
2	1	WM	4	0.00
2	1	WM	8	0.16
2	1	WM	12	0.26
2	1	WM	16	0.47
2	1	WM	20	0.54
2	1	WM	24	0.70
2	1	WM	28	0.77
2	1	WM	32	0.77
2	1	WM	36	0.61
2	1	WM	42	0.56
2	1	WM	48	0.44
2	1	WM	54	0.37
2	1	WM	60	0.28
2	1	WM	72	0.19
2	2	CONTROL	4	0.00
2	2	CONTROL	8	0.00
2	2	CONTROL	12	0.03
2	2	CONTROL	16	0.08
2	2	CONTROL	20	0.26
2	2	CONTROL	24	0.35
2	2	CONTROL	28	0.54
2	2	CONTROL	32	0.65
2	2	CONTROL	36	0.74
2	2	CONTROL	42	0.74
2	2	CONTROL	48	0.85
2	2	CONTROL	54	0.76
2	2	CONTROL	60	0.62
2	2	CONTROL	72	0.51

Ytterbium concentration (ppm) by steers fed different concentrate sources (Cont.).

PER	AN	TREAT	TIME	YBPPM	PER	AN	TREAT	TIME	YBPPM
2	3	CSBM	4	0.00	3	3	CONTROL	4	0.00
2	3	CSBM	8	0.03	3	3	CONTROL	8	0.00
2	3	CSBM	12	0.23	3	3	CONTROL	12	0.14
2	3	CSBM	16	0.48	3	3	CONTROL	16	0.34
2	3	CSBM	20	0.50	3	3	CONTROL	20	0.48
2	3	CSBM	24	0.56	3	3	CONTROL	24	0.69
2	3	CSBM	28	0.76	3	3	CONTROL	28	0.71
2	3	CSBM	32	0.69	3	3	CONTROL	32	0.73
2	3	CSBM	36	0.58	3	3	CONTROL	36	0.67
2	3	CSBM	42	0.51	3	3	CONTROL	42	0.52
2	3	CSBM	48	0.48	3	3	CONTROL	48	0.50
2	3	CSBM	54	0.42	3	3	CONTROL	54	0.38
2	3	CSBM	60	0.25	3	3	CONTROL	60	0.41
2	3	CSBM	72	0.19	3	3	CONTROL	72	0.29
2	4	SBH	4	0.00	3	4	WM	4	0.00
2	4	SBH	8	0.00	3	4	WM	8	0.02
2	4	SBH	12	0.16	3	4	WM	12	0.16
2	4	SBH	16	0.40	3	4	WM	16	0.41
2	4	SBH	20	0.55	3	4	WM	20	0.55
2	4	SBH	24	0.61	3	4	WM	24	0.62
2	4	SBH	28	0.70	3	4	WM	28	0.68
2	4	SBH	32	0.68	3	4	WM	32	0.62
2	4	SBH	36	0.53	3	4	WM	36	0.48
2	4	SBH	42	0.46	3	4	WM	42	0.40
2	4	SBH	48	0.41	3	4	WM	48	0.36
2	4	SBH	54	0.33	3	4	WM	54	0.32
2	4	SBH	60	0.25	3	4	WM	60	0.20
2	4	SBH	72	0.13	3	4	WM	72	0.15
3	1	SBH	4	0.00	4	1	CONTROL	4	0.00
3	1	SBH	8	0.11	4	1	CONTROL	8	0.00
3	1	SBH	12	0.45	4	1	CONTROL	12	0.12
3	1	SBH	16	0.68	4	1	CONTROL	16	0.20
3	1	SBH	20	0.76	4	1	CONTROL	20	0.33
3	1	SBH	24	0.88	4	1	CONTROL	24	0.63
3	1	SBH	28	0.88	4	1	CONTROL	28	0.76
3	1	SBH	32	0.80	4	1	CONTROL	32	0.81
3	1	SBH	36	0.70	4	1	CONTROL	36	0.82
3	1	SBH	42	0.59	4	1	CONTROL	42	0.86
3	1	SBH	48	0.56	4	1	CONTROL	48	0.92
3	1	SBH	54	0.39	4	1	CONTROL	54	0.75
3	1	SBH	60	0.26	4	1	CONTROL	60	0.67
3	1	SBH	72	0.25	4	1	CONTROL	72	0.55

Ytterbium concentration (ppm) by steers fed different concentrate sources (Cont.).

PER	AN	TREAT	TIME	YBPPM
4	3	WM	4	0.00
4	3	WM	8	0.00
4	3	WM	12	0.16
4	3	WM	16	0.29
4	3	WM	20	0.47
4	3	WM	24	0.50
4	3	WM	28	0.59
4	3	WM	32	0.66
4	3	WM	36	0.64
4	3	WM	42	0.47
4	3	WM	48	0.45
4	3	WM	54	0.47
4	3	WM	60	0.34
4	3	WM	72	0.22
4	4	CSBM	4	0.00
4	4	CSBM	8	0.00
4	4	CSBM	12	0.02
4	4	CSBM	16	0.14
4	4	CSBM	20	0.28
4	4	CSBM	24	0.46
4	4	CSBM	28	0.52
4	4	CSBM	32	0.64
4	4	CSBM	36	0.58
4	4	CSBM	42	0.53
4	4	CSBM	48	0.50
4	4	CSBM	54	0.48
4	4	CSBM	60	0.31
4	4	CSBM	72	0.30

Parameters and secondary variable estimates for large particles (Yb).

PER	AN	TREAT	CZERO	KPSLOW	TDELAY	DOSE	FASTMRT	SLOWMRT
1	4	CONTROL	103.3	0.0161	11.1	114.5	8.6	62.1
2	2	CONTROL	168.5	0.0299	7.0	114.5	25.0	33.4
3	3	CONTROL	116.7	0.0273	5.4	114.5	14.4	36.6
4	1	CONTROL	153.2	0.0227	3.9	117.0	23.2	44.1
1	1	CSBM	149.6	0.0426	0.0	114.5	20.8	23.5
2	3	CSBM	135.1	0.0365	1.1	114.5	18.8	27.4
4	4	CSBM	99.2	0.0254	7.6	117.0	16.4	39.4
1	3	SBH	185.1	0.0613	2.0	114.5	18.8	16.3
2	4	SBH	125.2	0.0386	4.2	114.5	15.1	25.9
3	1	SBH	167.7	0.0361	1.2	114.5	15.4	27.7
1	2	WM	136.8	0.0315	7.1	114.5	16.9	31.7
2	1	WM	165.8	0.0435	0.0	114.5	20.5	23.0
3	4	WM	92.2	0.0302	6.4	114.5	10.0	33.1
4	3	WM	121.2	0.0330	2.1	117.0	20.2	30.3

PER	AN	TREAT	TRMRT	DUODDMO	KPFASTC	FILLUDMS	FILLUDMF	TOTALFIL
1	4	CONTROL	81.8	0.4283	0.1899	1.11	0.09	1.20
2	2	CONTROL	65.4	0.4875	0.0655	0.68	0.31	0.99
3	3	CONTROL	56.4	0.6428	0.1136	0.98	0.24	1.22
4	1	CONTROL	71.1	0.4161	0.0705	0.76	0.25	1.01
1	1	CSBM	44.3	0.7823	0.0785	0.77	0.42	1.18
2	3	CSBM	47.3	0.7426	0.0871	0.85	0.36	1.20
4	4	CSBM	63.4	0.7190	0.0994	1.18	0.30	1.48
1	3	SBH	37.1	0.9101	0.0871	0.62	0.44	1.05
2	4	SBH	45.2	0.8472	0.1082	0.91	0.33	1.24
3	1	SBH	44.3	0.5917	0.1062	0.68	0.23	0.92
1	2	WM	55.7	0.6329	0.0967	0.84	0.27	1.11
2	1	WM	43.5	0.7208	0.0798	0.69	0.38	1.07
3	4	WM	49.5	0.8997	0.1642	1.24	0.23	1.47
4	3	WM	52.6	0.7647	0.0807	0.97	0.39	1.36

Ammonia concentration (mg dL) by steers fed different concentrate sources.

PER	AN	TREAT	TIME	AMMONIA
1	1	CSBM	2	3.37
1	1	CSBM	4	0.68
1	1	CSBM	6	0.53
1	1	CSBM	8	0.50
1	1	CSBM	12	1.03
1	1	CSBM	18	0.58
1	1	CSBM	24	2.56
1	2	WM	2	15.95
1	2	WM	4	14.97
1	2	WM	6	6.22
1	2	WM	8	7.30
1	2	WM	12	2.54
1	2	WM	18	1.87
1	2	WM	24	2.12
1	3	SBH	2	9.38
1	3	SBH	4	5.41
1	3	SBH	6	1.60
1	3	SBH	8	1.07
1	3	SBH	12	0.78
1	3	SBH	18	0.63
1	3	SBH	24	1.80
1	4	CONTROL	2	1.70
1	4	CONTROL	4	3.59
1	4	CONTROL	6	1.51
1	4	CONTROL	8	0.92
1	4	CONTROL	12	0.88
1	4	CONTROL	18	1.31
1	4	CONTROL	24	1.02
2	1	WM	2	17.93
2	1	WM	4	12.69
2	1	WM	6	5.57
2	1	WM	8	4.02
2	1	WM	12	7.77
2	1	WM	18	4.61
2	1	WM	24	6.97
2	2	CONTROL	2	5.78
2	2	CONTROL	4	7.19
2	2	CONTROL	6	5.96
2	2	CONTROL	8	2.85
2	2	CONTROL	12	0.97
2	2	CONTROL	18	0.65
2	2	CONTROL	24	1.18
2	3	CSBM	2	6.33
2	3	CSBM	4	0.81
2	3	CSBM	6	2.03
2	3	CSBM	8	1.18
2	3	CSBM	12	1.11
2	3	CSBM	18	1.15
2	3	CSBM	24	1.37
2	4	SBH	2	7.73
2	4	SBH	4	3.81
2	4	SBH	6	2.05
2	4	SBH	8	1.60
2	4	SBH	12	1.59
2	4	SBH	18	1.89
2	4	SBH	24	3.68
3	1	SBH	2	12.42
3	1	SBH	4	8.51
3	1	SBH	6	1.91
3	1	SBH	8	1.66
3	1	SBH	12	1.88
3	1	SBH	18	2.24
3	1	SBH	24	5.09
3	3	CONTROL	2	3.46
3	3	CONTROL	4	6.24
3	3	CONTROL	6	3.94
3	3	CONTROL	8	1.02
3	3	CONTROL	12	0.67
3	3	CONTROL	18	1.17
3	3	CONTROL	24	1.54
3	4	WM	2	10.18
3	4	WM	4	8.47
3	4	WM	6	5.28
3	4	WM	8	6.96
3	4	WM	12	7.88
3	4	WM	18	4.33
3	4	WM	24	5.56
4	1	CONTROL	2	5.73
4	1	CONTROL	4	5.35
4	1	CONTROL	6	3.04
4	1	CONTROL	8	1.71
4	1	CONTROL	12	1.09
4	1	CONTROL	18	0.68
4	1	CONTROL	24	1.50
4	3	WM	2	20.40
4	3	WM	4	16.64
4	3	WM	6	9.52
4	3	WM	8	5.28
4	3	WM	12	5.48
4	3	WM	18	3.67
4	3	WM	24	3.85
4	4	CSBM	2	1.32
4	4	CSBM	4	1.73
4	4	CSBM	6	1.46
4	4	CSBM	8	0.77
4	4	CSBM	12	1.32
4	4	CSBM	18	2.31
4	4	CSBM	24	3.13

Rumen fluid pH by steers fed different concentrate sources.

PER	AN	TREAT	TIME	pH	PER	AN	TREAT	TIME	pH
1	1	CSBM	2	6.9	2	4	SBH	2	6.8
1	1	CSBM	4	6.4	2	4	SBH	4	6.6
1	1	CSBM	6	6.3	2	4	SBH	6	6.6
1	1	CSBM	8	6.4	2	4	SBH	8	6.3
1	1	CSBM	12	6.5	2	4	SBH	12	6.5
1	1	CSBM	18	6.5	2	4	SBH	18	6.9
1	1	CSBM	24	7.1	2	4	SBH	24	7.0
1	2	WM	2	6.8	3	1	SBH	2	6.7
1	2	WM	4	6.6	3	1	SBH	4	6.8
1	2	WM	6	6.3	3	1	SBH	6	6.6
1	2	WM	8	6.4	3	1	SBH	8	6.6
1	2	WM	12	6.4	3	1	SBH	12	6.6
1	2	WM	18	6.5	3	1	SBH	18	6.7
1	2	WM	24	6.9	3	1	SBH	24	6.9
1	3	SBH	2	7.4	3	3	CONTROL	2	6.9
1	3	SBH	4	6.8	3	3	CONTROL	4	6.9
1	3	SBH	6	6.7	3	3	CONTROL	6	6.9
1	3	SBH	8	6.5	3	3	CONTROL	8	6.7
1	3	SBH	12	6.4	3	3	CONTROL	12	6.7
1	3	SBH	18	6.6	3	3	CONTROL	18	6.8
1	3	SBH	24	7.1	3	3	CONTROL	24	6.9
1	4	CONTROL	2	7.5	3	4	WM	2	6.3
1	4	CONTROL	4	7.2	3	4	WM	4	6.2
1	4	CONTROL	6	6.9	3	4	WM	6	6.4
1	4	CONTROL	8	6.8	3	4	WM	8	6.7
1	4	CONTROL	12	6.7	3	4	WM	12	6.8
1	4	CONTROL	18	6.6	3	4	WM	18	6.9
1	4	CONTROL	24	7.0	3	4	WM	24	7.0
2	1	WM	2	6.6	4	1	CONTROL	2	6.8
2	1	WM	4	6.3	4	1	CONTROL	4	6.8
2	1	WM	6	6.3	4	1	CONTROL	6	6.8
2	1	WM	8	6.4	4	1	CONTROL	8	6.8
2	1	WM	12	6.5	4	1	CONTROL	12	6.7
2	1	WM	18	6.9	4	1	CONTROL	18	6.7
2	1	WM	24	7.1	4	1	CONTROL	24	6.9
2	2	CONTROL	2	6.8	4	3	WM	2	6.5
2	2	CONTROL	4	6.7	4	3	WM	4	6.3
2	2	CONTROL	6	6.7	4	3	WM	6	6.5
2	2	CONTROL	8	6.6	4	3	WM	8	6.5
2	2	CONTROL	12	6.4	4	3	WM	12	6.6
2	2	CONTROL	18	6.5	4	3	WM	18	6.8
2	2	CONTROL	24	6.7	4	3	WM	24	7.0
2	3	CSBM	2	6.9	4	4	CSBM	2	6.3
2	3	CSBM	4	5.8	4	4	CSBM	4	6.4
2	3	CSBM	6	6.2	4	4	CSBM	6	6.5
2	3	CSBM	8	6.6	4	4	CSBM	8	6.6
2	3	CSBM	12	6.7	4	4	CSBM	12	6.8
2	3	CSBM	18	6.9	4	4	CSBM	18	6.9
2	3	CSBM	24	7.0	4	4	CSBM	24	7.0

Production of volatile fatty acids (mM) by steers fed different concentrate sources.

PER	AN	TREAT	TIME	TOTAL	ACETIC	PROPION	BUTYRIC	OTHER
1	1	CSBM	2	64.33	42.58	12.46	5.73	3.56
1	1	CSBM	4	89.51	58.50	20.54	8.00	2.48
1	1	CSBM	6	51.50	32.39	12.81	4.72	1.58
1	1	CSBM	8	87.98	53.90	23.75	8.34	1.99
1	1	CSBM	12	68.71	42.20	18.25	6.61	1.64
1	1	CSBM	18	65.83	43.89	14.81	5.73	1.40
1	1	CSBM	24	70.56	46.83	15.92	6.01	1.79
1	2	WM	2	75.84	46.02	17.36	9.14	3.31
1	2	WM	4	80.58	49.78	18.69	10.20	1.91
1	2	WM	6	47.42	27.13	12.00	7.15	1.14
1	2	WM	8	69.10	41.09	16.90	9.66	1.44
1	2	WM	12	33.72	20.46	7.44	4.90	0.91
1	2	WM	18	53.28	34.18	13.04	5.10	0.98
1	2	WM	24	35.96	23.39	8.85	2.87	0.85
1	3	SBH	2	80.55	54.77	15.89	6.87	3.01
1	3	SBH	4	69.36	48.21	13.68	5.89	1.58
1	3	SBH	6	86.67	60.34	17.89	7.12	1.33
1	3	SBH	8	90.58	61.87	19.83	7.86	1.02
1	3	SBH	12	87.25	59.52	19.52	7.41	0.80
1	3	SBH	18	77.34	52.84	17.11	6.51	0.88
1	3	SBH	24	70.95	52.76	12.66	4.77	0.75
1	4	CONTROL	2	75.99	50.15	17.18	6.34	2.32
1	4	CONTROL	4	66.63	44.89	14.40	5.78	1.55
1	4	CONTROL	6	70.62	46.58	16.37	6.36	1.30
1	4	CONTROL	8	57.74	38.76	12.77	5.24	0.97
1	4	CONTROL	12	60.52	39.79	14.31	5.63	0.79
1	4	CONTROL	18	65.75	40.16	18.82	5.81	0.95
1	4	CONTROL	24	71.37	50.32	15.36	4.88	0.82
2	1	WM	2	115.01	68.56	35.13	8.92	2.39
2	1	WM	4	118.12	70.42	33.94	11.54	2.22
2	1	WM	6	97.79	56.91	29.40	10.12	1.36
2	1	WM	8	90.18	61.13	20.50	7.45	1.10
2	1	WM	12	81.20	48.97	24.00	7.15	1.08
2	1	WM	18	73.17	48.40	17.59	5.89	1.30
2	1	WM	24	69.06	48.87	14.58	4.43	1.18
2	2	CONTROL	2	48.50	36.86	6.37	3.13	2.14
2	2	CONTROL	4	49.08	37.89	6.56	3.35	1.28
2	2	CONTROL	6	46.49	35.27	6.50	3.71	1.02
2	2	CONTROL	8	51.10	38.36	7.76	4.04	0.93
2	2	CONTROL	12	54.97	40.03	9.65	4.54	0.76
2	2	CONTROL	18	49.46	35.70	9.55	3.51	0.70
2	2	CONTROL	24	64.99	46.50	13.36	4.01	1.11
2	3	CSBM	2	90.24	65.70	15.83	6.84	1.87
2	3	CSBM	4	95.10	70.95	16.15	6.96	1.04
2	3	CSBM	6	85.43	63.07	15.50	6.07	0.79
2	3	CSBM	8	76.69	49.98	19.44	6.38	0.90
2	3	CSBM	12	68.86	45.71	15.89	6.39	0.87
2	3	CSBM	18	76.67	52.46	17.18	5.75	1.27
2	3	CSBM	24	67.06	48.06	13.64	4.12	1.24

Production of volatile fatty acids (mM) by steers fed different concentrate sources (Cont.).

PER	AN	TREAT	TIME	TOTAL	ACETIC	PROPION	BUTYRIC	OTHER
2	4	SBH	2	90.10	62.92	18.49	6.69	1.99
2	4	SBH	4	87.79	61.83	17.67	6.89	1.41
2	4	SBH	6	84.70	59.44	17.18	6.95	1.13
2	4	SBH	8	98.74	68.69	20.41	8.41	1.23
2	4	SBH	12	96.08	66.58	20.02	8.46	1.02
2	4	SBH	18	85.73	59.42	17.94	7.25	1.12
2	4	SBH	24	71.74	50.17	14.66	5.81	1.11
3	1	SBH	2	87.37	62.68	16.59	5.78	2.32
3	1	SBH	4	86.83	62.43	16.51	5.81	2.08
3	1	SBH	6	79.56	56.97	15.79	5.33	1.47
3	1	SBH	8	89.14	63.55	17.96	6.17	1.46
3	1	SBH	12	95.40	68.93	18.45	6.70	1.31
3	1	SBH	18	89.21	64.39	17.15	6.20	1.48
3	1	SBH	24	75.28	54.63	13.82	5.22	1.60
3	3	CONTROL	2	35.39	25.88	5.88	2.03	1.59
3	3	CONTROL	4	55.64	43.14	7.56	3.77	1.17
3	3	CONTROL	6	51.56	38.52	8.71	3.42	0.92
3	3	CONTROL	8	48.84	37.04	7.88	3.23	0.68
3	3	CONTROL	12	33.02	23.86	6.37	2.39	0.41
3	3	CONTROL	18	63.44	45.79	13.32	3.62	0.71
3	3	CONTROL	24	68.50	50.71	13.94	3.18	0.67
3	4	WM	2	84.65	54.95	20.00	7.18	2.52
3	4	WM	4	120.35	78.03	27.60	12.28	2.44
3	4	WM	6	69.64	46.27	15.08	6.76	1.53
3	4	WM	8	60.32	39.81	13.00	6.06	1.44
3	4	WM	12	75.16	49.15	17.03	7.10	1.88
3	4	WM	18	59.50	39.81	13.88	4.35	1.46
3	4	WM	24	69.11	47.36	15.67	4.40	1.67
4	1	CONTROL	2	72.26	51.34	12.00	6.11	2.80
4	1	CONTROL	4	69.39	49.72	11.70	5.83	2.15
4	1	CONTROL	6	71.13	49.11	12.59	7.39	2.03
4	1	CONTROL	8	65.95	45.64	11.88	6.95	1.48
4	1	CONTROL	12	50.52	34.46	9.82	5.37	0.87
4	1	CONTROL	18	74.02	52.70	13.78	6.31	1.22
4	1	CONTROL	24	46.18	32.00	9.28	3.97	0.92
4	3	WM	2	118.19	73.69	27.39	14.37	2.74
4	3	WM	4	109.01	68.37	26.30	12.15	2.19
4	3	WM	6	100.50	64.74	21.95	11.86	1.94
4	3	WM	8	88.15	56.22	19.69	10.93	1.31
4	3	WM	12	84.38	54.91	18.34	10.06	1.08
4	3	WM	18	79.57	51.13	18.42	8.92	1.10
4	3	WM	24	41.84	26.73	9.97	4.39	0.75
4	4	CSBM	2	111.26	70.78	26.99	11.26	2.23
4	4	CSBM	4	105.34	68.75	23.65	11.14	1.81
4	4	CSBM	6	104.37	68.26	21.97	12.59	1.55
4	4	CSBM	8	92.66	58.39	20.83	11.88	1.56
4	4	CSBM	12	70.67	47.39	13.67	8.35	1.26
4	4	CSBM	18	69.00	42.07	19.16	6.42	1.35
4	4	CSBM	24	60.60	38.62	15.89	5.02	1.08

Cobalt concentration (ppm) by steers fed different concentrate sources.

PER	AN	TREAT	TIME	COPPM
1	1	CSBM	2	107.9
1	1	CSBM	4	107.6
1	1	CSBM	6	43.4
1	1	CSBM	8	60.4
1	1	CSBM	12	33.3
1	1	CSBM	18	34.6
1	1	CSBM	24	17.7
1	2	WM	2	217.8
1	2	WM	4	184.0
1	2	WM	6	81.0
1	2	WM	8	114.7
1	2	WM	12	43.8
1	2	WM	18	41.2
1	2	WM	24	19.8
1	3	SBH	2	162.4
1	3	SBH	4	105.0
1	3	SBH	6	95.4
1	3	SBH	8	78.8
1	3	SBH	12	43.6
1	3	SBH	18	23.1
1	3	SBH	24	16.7
1	4	CONTROL	2	133.9
1	4	CONTROL	4	167.1
1	4	CONTROL	6	140.5
1	4	CONTROL	8	87.0
1	4	CONTROL	12	51.6
1	4	CONTROL	18	19.1
1	4	CONTROL	24	28.8
2	1	WM	2	198.1
2	1	WM	4	154.3
2	1	WM	6	105.7
2	1	WM	8	90.1
2	1	WM	12	57.0
2	1	WM	18	32.5
2	1	WM	24	22.8
2	2	CONTROL	2	190.9
2	2	CONTROL	4	185.7
2	2	CONTROL	6	157.9
2	2	CONTROL	8	144.0
2	2	CONTROL	12	120.4
2	2	CONTROL	18	85.4
2	2	CONTROL	24	104.7
2	3	CSBM	2	208.2
2	3	CSBM	4	149.6
2	3	CSBM	6	112.5
2	3	CSBM	8	78.9
2	3	CSBM	12	48.4
2	3	CSBM	18	33.2
2	3	CSBM	24	20.2
2	4	SBH	2	286.2
2	4	SBH	4	168.3
2	4	SBH	6	101.4
2	4	SBH	8	97.5
2	4	SBH	12	64.1
2	4	SBH	18	39.5
2	4	SBH	24	19.1
3	1	SBH	2	266.4
3	1	SBH	4	76.6
3	1	SBH	6	51.0
3	1	SBH	8	55.0
3	1	SBH	12	28.0
3	1	SBH	18	19.9
3	1	SBH	24	12.0
3	3	CONTROL	2	61.1
3	3	CONTROL	4	69.1
3	3	CONTROL	6	55.8
3	3	CONTROL	8	40.5
3	3	CONTROL	12	18.4
3	3	CONTROL	18	18.6
3	3	CONTROL	24	14.0
3	4	WM	2	88.4
3	4	WM	4	69.4
3	4	WM	6	54.7
3	4	WM	8	39.0
3	4	WM	12	33.1
3	4	WM	18	21.3
3	4	WM	24	13.9
4	1	CONTROL	2	202.0
4	1	CONTROL	4	106.4
4	1	CONTROL	6	75.6
4	1	CONTROL	8	66.6
4	1	CONTROL	12	35.3
4	1	CONTROL	18	31.3
4	1	CONTROL	24	13.1
4	3	WM	2	122.4
4	3	WM	4	82.0
4	3	WM	6	56.7
4	3	WM	8	44.1
4	3	WM	12	34.3
4	3	WM	18	18.7
4	3	WM	24	7.0
4	4	CSBM	2	142.5
4	4	CSBM	4	93.5
4	4	CSBM	6	65.2
4	4	CSBM	8	59.3
4	4	CSBM	12	34.6
4	4	CSBM	18	17.4
4	4	CSBM	24	11.6

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BIOGRAPHICAL SKETCH

Pedro Garcés Yépez was born on March 27 1952, in México City. He was raised in México where he received his B.S. degree in veterinary medicine from the National University of México in 1970. Upon graduation Pedro enter the Graduate School of the National University of México and received his M.S. degree in Animal Nutrition in 1978.

In México, Pedro worked for the National Institute of Livestock Research of the Ministry of Agriculture as an associate researcher in the field of ruminant nutrition, in the area of utilization of agriculture byproducts by livestock.

Pedro enrolled at the University of Florida in the fall of 1990. He is currently a candidate for the Doctor of Philosophy degree.

Pedro is married to María del Carmen Torres and they have two children, Mercedes and Rodrigo Salvador.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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